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Sigma-Phase Embrittlement in 25Cr–20Ni Heat-Resisting Steels

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SYNOPSIS

Metallurgical observations relating to the occurrence of sigma phase in ferrite-free 25% chromium–20% nickel bar steels are presented. Particular attention is paid to the effect of variable grain size, arising from different annealing temperatures, on the distribution of the constituents, on their rates of precipitation, and on the tensile and impact properties of the steels after the complete precipitation of the carbide and sigma phases. As much as 10–15% of carbide and sigma phases may be present in fine-grained steels without serious loss of tensile ductility, but moderate grain coarsening, such as might arise from a 100° C. difference in the prior-annealing temperature, will result in the almost complete loss of tensile ductility and impact resistance in the presence of the same amount of sigma. Data are presented to show how the composition of the steels may be adjusted to reduce their sigma content if this is considered necessary.

Introduction

THIS paper is based on the results of individual investigations carried out over a long period on the now standard 25% chromium–20% nickel steel, and deals mainly with sigma-phase formation at elevated temperatures and its influence on mechanical properties.

Wrought bar, normally heat-treated by air cooling or water quenching from 1050–1150° C., is austenitic and entirely free from ferrite. Chromium carbides may be present in amounts depending upon the carbon content of the steel and the annealing or solution treatment. The austenite has high stability at room temperature. Even after substantial cold work, *e.g.*, 20% elongation, commercial casts of this steel are still free from ferrite and are non-ferromagnetic (permeability 1·002).

There is now ample evidence that σ forms in austenitic steels that are free from ferrite at the annealing temperatures.[1, 2, 3] The relative rates of σ formation may differ considerably, often being slower from austenite than from ferrite, although this depends on the steel composition.

Several papers make it clear that commercial 25/20 steel is unstable below about 925–1000° C., depending on the silicon content, the equilibrium phases being austenite, σ, and chromium carbide. Therefore, if the annealed steel is heated for long periods in the range 950–550° C., or perhaps even at lower temperatures, σ will precipitate from the austenite. Recent work[4] has also shown that austenite and σ are stable in a virtually pure 25% Cr–20% Ni alloy at 650° and 800° C.

The influence of elements other than Ni and Cr on the susceptibility to σ formation does not appear to have been thoroughly investigated, although there is some evidence that silicon is a potent σ-forming element in steels of this type.[5] The present paper deals more fully with the effect of changes in the steel composition on the amount of σ formed, and indicates how these and variations in the initial heat-treatment may influence the extent of σ embrittlement. The term 'embrittlement' is used to denote the extent to which the ample ductility of the steel as annealed is reduced by long periods of heating below the annealing temperature, and does not necessarily imply a condition of brittleness, *i.e.*, complete loss of tensile ductility.

PROCEDURE

Microscopic and X-ray examinations were used throughout as aids to the detection of sigma in both solid specimens and chemically extracted residues.

Tensile and Izod impact tests were carried out on a selection of the steels, a few of which were commercial bar stock, the remainder being $\frac{3}{4}$-in. dia. bars produced from 30-lb. induction furnace melts.

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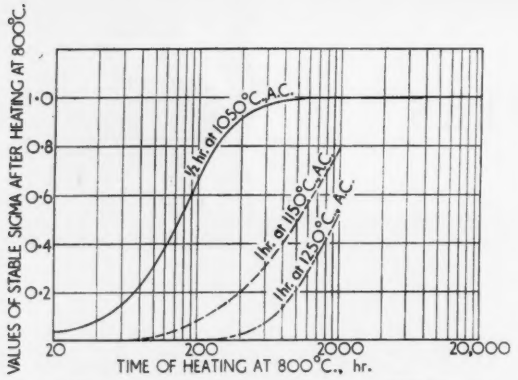

Fig. 1—Rate of sigma formation at 800° C. in a 25Cr/20Ni bar steel (Steel *A*), according to initial softening temperature. Stable σ content 10 vol.-%

SIGMA FORMATION IN A TYPICAL COMMERCIAL STEEL

Preliminary Trials

The material (steel *A*) has the composition: 0·12% of C; 1·46% of Si; 0·79% of Mn; 21·00% of Ni; and 24·23% of Cr, and was A.C. at 1050° C.

Discs were cut from ¾-in. dia. bars and exposed for 200 hr. at temperatures in the range 650–950° C., at 50° C. intervals. The results obtained were as follows:

Temp. of Exposure, °C.	Sigma, %	30 kg. Diamond Hardness
650	Trace	163
700	2	167
750	5	174
800	6	167
850	6	167
900	1	157
950	Nil	154

The σ is precipitated in the grain boundaries (*see* Fig. 5*b*). At 750° C. and above, individual precipitates are massive in comparison with, for example, chromium carbide, and can readily be seen at a magnification of 200. Little hardening occurs, the steel, as softened by air cooling from 1050° C., having a 30 kg. diamond hardness of 150.

Stability at 800° C.

The results of the mechanical tests carried out after exposure for various periods up to 8000 hr. at 800° C. are given in Table I.

There is a large drop in impact value during the first 200 hr. of exposure at 800° C. Thereafter, the rate of drop is substantially slower, some form of equilibrium being reached after 500–1000 hr. of exposure. Elongation and reduction in area are also affected, but not so markedly, with again some stability after 500–1000 hr. Previous investigators have noted that σ appears to have little influence on yield point, maximum stress, and hardness values of wrought steels,[6, 7, 8] and the present results confirm this.

As would be expected from the mechanical test results, the first 500 hr. of exposure at 800° C. account for practically all the σ observed during the whole 8000-hr. test period.

The 25/20 steels are often put into service after softening at 1050° C., followed by air cooling. At 1050° C., the stable structure is face-centred cubic austenite and chromium carbide. Figure 3*a* shows the typical microstructure of a bar softened by a treatment of 1050° C., A.C. Most of the carbide shown was undissolved at 1050° C.

Little additional carbide was precipitated in specimens subsequently heated at 800° C., suggesting only a small change in carbide solubility. Traces of this new carbide precipitation can be seen in the grain boundaries (*see* Fig. 3*b*). After the first day at 800° C., σ appears in the grain boundaries. The two constituents can be distinguished in the microstructures shown in Fig. 3 by the selective attack of the etching reagent (*aqua regia*) on the σ. This has been dissolved from the surface, leaving non-reflecting pits identical in surface area with the individual particles of sigma. The chromium carbide is not attacked and is left in slight relief.*

As shown in Fig. 3*c*, the steel contains about 10% of σ after 1000 hr. of heating at 800° C. This is apparently the stable structure of the steel at this temperature, since longer exposures do not apparently produce more of this constituent. Specimens heated for 1000 hr. or longer at 800° C., however, showed

* The identity of both chromium carbide ($Cr_{23}C_6$) and σ was established by X-ray diffraction examination of residues extracted electrolytically, using the citric acid and potassium iodide electrolyte.

Table I

MECHANICAL PROPERTIES OF STEEL *A* AFTER EXPOSURE AT 800° C. FOR VARYING PERIODS

Time of Exposure at 800° C., hr.	Microstructure	Yield Point (Tons/sq. in.)	Max. Stress (Tons/sq. in.)	Elong., %	Red. in A., %	Brinell 3000 kg. 10 mm. ball	Izod, ft.lb.
Nil	γ + 1·5% carbide	24·0	45·3	49	62	179	120
200	γ + 2% carbide + 6% σ	21·8	44·8	36	43	184	23
500	γ + 2% carbide + 9% σ	22·7	45·0	32½	36	198	18
1000	γ + 2% carbide + 10% σ	21·9	43·1	32	38½	191	14
2000	γ + 2% carbide + 10% σ	...	...	...	...	192	...
8000	γ + 2% carbide + 10% σ	25·5	42·5	32	35	...	13

Carbide ($Cr_{23}C_6$) calculated as vol.-% of steel, assuming: (*a*) 0·06% of carbon soluble at 1050° C.
(*b*) 0·04% " " " " 800° C.
(*c*) 30% of chromium in carbide replaced by iron
(*d*) Density of carbide is 5·5 g./c.c.

Sigma—estimated as vol.-% of steel using the procedure described by Howard and Cohen[5]

that both carbides and σ particles tend to become fewer and more massive, the latter adopting a pronounced angular form, as in Fig. 3*d*. This must involve local solution and reprecipitation, as stable σ grains are produced from the initial dispersed precipitates.

Four other steels of similar type, but with different cast analyses, were randomly selected from bar stock and tested before and after 2000 hr. at 800° C. The results were substantially similar, although in two cases 16% of σ formed and the elongation was reduced to 20%. Bend test pieces ($\frac{3}{8}$ in. × $\frac{3}{32}$ in.) broke at 180°, 65°, and 21° with 0, 11%, and 16% of σ respectively (bent over $d = 3t$).

SOME EFFECTS OF INITIAL HEAT-TREATMENT

The previous results suggest that the extent of embrittlement in a 1050° C. annealed steel is determined largely by the amount of sigma formed from the austenite during subsequent heating. The extent to which the rate of σ precipitation is influenced by different initial heat-treatments is, therefore, of interest.

The work of Emmanuel[7] and other investigators has indicated that higher annealing temperatures, which are accompanied by grain coarsening, decrease the rate of σ formation on subsequent heating. It is not clear, however, whether the amount of σ ultimately formed is the same whatever the prior annealing temperature, given sufficient time for equilibrium in the σ-forming range. Bar specimens of steel *A*, initially treated at 1050°, 1150° or 1250° C. for $\frac{1}{2}$ or 1 hr. and A.C., were subsequently heated at 800° C., the rate of σ formation being assessed by microexamination.

The results given in Fig. 1 show that annealing at temperatures higher than 1050° C. caused slower precipitation of σ at 800° C. in steel *A*; only about half as much σ appeared in the 1250° C. treated specimen during 2000 hr. at 800° C. as after 1000 hr. at 800° C. in the specimen originally softened at 1050° C.

Ductility after Ageing

Although the above results suggested that softening at 1150° instead of 1050° C. might give a slower rate of σ embrittlement, the tensile tests on a similar steel *B* (*see* Table II) did not bear this out. Steel *B* has the following composition: 0·14% of C; 1·30% of Si; 0·60% of Mn; 20·9% of Ni; and 25·0% of Cr.

Sigma again formed more slowly in the 1150° C. annealed specimens, but the rate of embrittlement was greater.

Although equal amounts of σ occurred after 8000 hr. at 800° C. in both 1050° and 1150° C. annealed specimens, the latter were more seriously embrittled. The amount of σ was clearly not the sole criterion of the extent of embrittlement.

Figure 2 shows the result of mechanical tests on a third cast, steel *C*, with the following composition: 0·08% of C; 1·77% of Si; 0·85 of Mn; 21·0% of Ni; 24·5% of Cr. These confirmed that the σ embrittlement arising from long periods at 800° C. was more severe in specimens annealed at 1150° C. than in

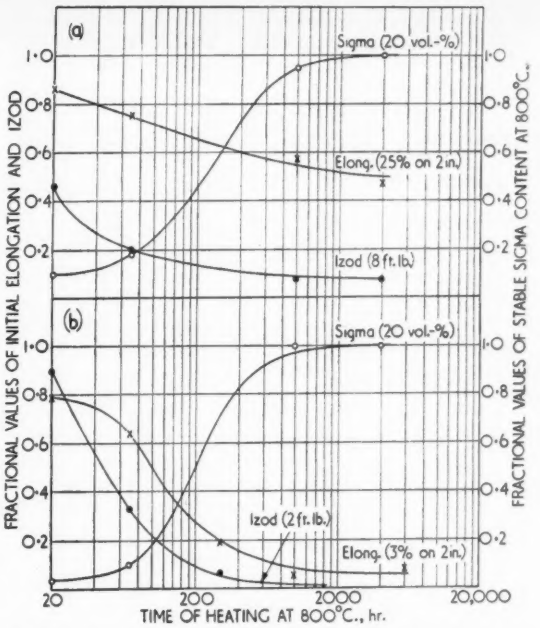

Fig. 2—Effect of prior annealing on ductility of Steel *C* after heating at 800° C.: (*a*) ½ hr. at 1050° C., A.C.; (*b*) 1 hr. at 1150° C , A.C.

Table II

RESULTS OF TENSILE TESTS ON STEEL *B*

Heat-Treatment	0·5% Proof Stress (Tons/sq. in.)	U.T.S. (Tons/sq. in.)	Elong., %	Red. in A., %	Izod, ft.lb.	Sigma, vol.-%
A.C. 1050° C.	22·1	43·8	50	61	113	Nil
,, ,, + 350 hr. 800° C.	20·5	42·1	31	25	12	6
,, ,, + 1000 hr. 800° C.	21·0	41·0	20	17	6	12
,, ,, + 8000 hr. 800° C.	20·9	35·9	19	14½	5	14
A.C. 1150° C.	18·6	42·8	58	65	120	Nil
,, ,, + 350 hr. 800° C.	20·9	43·7	20	17	5	4
,, ,, + 1000 hr. 800° C.	21·1	35·0	6	4	3	8
,, ,, + 8000 hr. 800° C.	22·3	29·5	3	1	1	14

others annealed at 1050° C. This steel, however, unlike *A* and *B*, precipitated σ at about the same rate in both cases. More σ was present in steel *C* than in steels *A* and *B*.

To summarize, initial softening at 1150° C. ultimately caused greater embrittlement. Although in some steels it slowed down the rate of σ formation, in another it had little influence.

Distribution of Sigma

The distribution of the σ formed at 800° C. is considerably influenced by the prior heat-treatment, but only in so far as this affects the grain size. This will be clear from the results obtained on three steels previously annealed at 1050° C. and 1150° C., details of which were as follows:

	Steel *C*	Steel *B*	Steel *D*
C, %	0·08	0·14	0·21
Si, %	1·77	1·30	2·20
Mn, %	0·85	0·60	0·80
Ni, %	21·0	20·9	21·0
Cr, %	24·5	25·0	24·8
A.S.T.M. grain size			
1050° C. softened	7	8	8
1150° C. softened	2	4	7

The characteristic granular formation of the σ found in the fine-grained specimen of steel *B*, annealed at 1050° C., is shown in Fig. 4*a*. The 1150° C. annealing treatment, however, dissolved the carbides and coarsened the grain size. The σ formed during subsequent heating at 800° C. appeared first in the grain boundaries and later on certain crystallographic planes within the grains, as shown in Fig. 4*b*. The carbides present were precipitated during treatment at 800° C.

An acicular precipitation of σ also occurred at 800° C. in steel *C* when in the coarse-grained condition arising from annealing at 1150° C. (*see* Fig. 4*c*). The same steel, however, when fine-grained (*i.e.*, 1050° C. condition) developed a microstructure similar to that shown in Fig. 4*a*.

On the other hand, steel *D*, with its 0·21% of C, remained in a fine-grained condition after annealing at 1150° C., presumably owing to the obstruction caused by undissolved carbides. On subsequent heating at 800° C., this specimen precipitated σ in the granular form shown in Fig. 4*d*, which is usually found in specimens pretreated at 1050° C. Thus, grain size rather than any initial solution effect appears to determine the form and distribution of σ.

In both the coarse- and fine-grained steels, σ precipitated most readily in the grain boundaries, as would be expected from consideration of the disorder and high free energies of the boundary positions. The most favoured site was at the junction of three grains, where it was usual to find a relatively large pool of σ (*see* Fig. 5*b*); such sites are numerous in fine-grained steels.

The proportion of the total precipitation that can occupy grain-boundary sites depends on the rates of diffusion of the participating elements as well as on grain size. For the diffusion rates applicable to any one temperature there will be a critical grain size below which all points within an individual grain can contribute to grain-boundary precipitates. Above this critical grain size there will be a need for intragranular nucleation.

In the 25/20 bar steels with an A.S.T.M. grain size of 7 and 8, such as those annealed at 1050° C., all the σ at 800° C. occurred in the grain boundaries, often at their intersections, in a granular or equiaxed form. As much as 18% can be precipitated in this way. Because these granular precipitates are relatively massive, a large proportion of the grain-boundary area was free from precipitation; this is believed to explain the limited effect of σ on the tensile ductility of the fine-grained steels.

The coarser-grained steels, such as those treated at 1150° C., with an A.S.T.M. grain size of 2–3, carried only a proportion of their σ precipitates in the grain boundaries (about 5 vol.-% of the steel). Amounts of σ in excess of 5% were precipitated at 800° C. inside the grains. These intragranular precipitates of σ took the form of continuous sheets or laths marking certain crystallographic planes (*see* Fig. 4*c*). Moreover, the grain-boundary σ in the coarse-grained steels was plate-like rather than granular, and more effectively separated the grains. This is shown by Fig. 5*a* and is believed to explain the severe embrittlement produced by even small amounts of σ in coarse-grained steels.

Figure 6 shows the effect of heating temperature on the form and distribution of σ. As already explained, there is a favourable balance between the rates of diffusion and grain size in a 1050° C. annealed 25/20 steel heated at 800° C., leading to granular precipitation. Lower temperatures, where diffusion of Cr is slower, change this condition, so that if the heat-treatment is carried out at 700° C., precipitation also occurs within the grains, even with the same fine grain size.

To check the influence of acicular σ precipitates within the grains, a comparison was made of tensile tests on fine-grained material having granular grain-boundary precipitates only (Fig. 6*b*), and on similar material containing both forms (Fig. 6*d*).

	A.C. 1050° C. + 1000 hr. at:	
Steel *C*	800° C.	700° C.
0·5% proof stress, tons/sq. in.	21·6	22·8
U.T.S., tons/sq. in.	44·2	44·2
Elongation, %	29	27
Reduction in area, %	29	25
Izod, ft.lb.	12	7

Although the steel had probably not reached full equilibrium at 700° C., the comparison suggests that the acicular precipitates have no severe embrittling effect. The severe embrittlement of coarse-grained steels containing both forms of precipitate probably results mainly from the semi-continuous grain-boundary σ of such steels. Subsequent results led to the same conclusion.

Rate of Sigma Precipitation

In some steels, higher-temperature softening retards the rate of σ formation and influences the amount of carbide precipitation. It is therefore necessary to consider how far these two effects may be related.

Metallographic experience of some 25 Cr–20 Ni

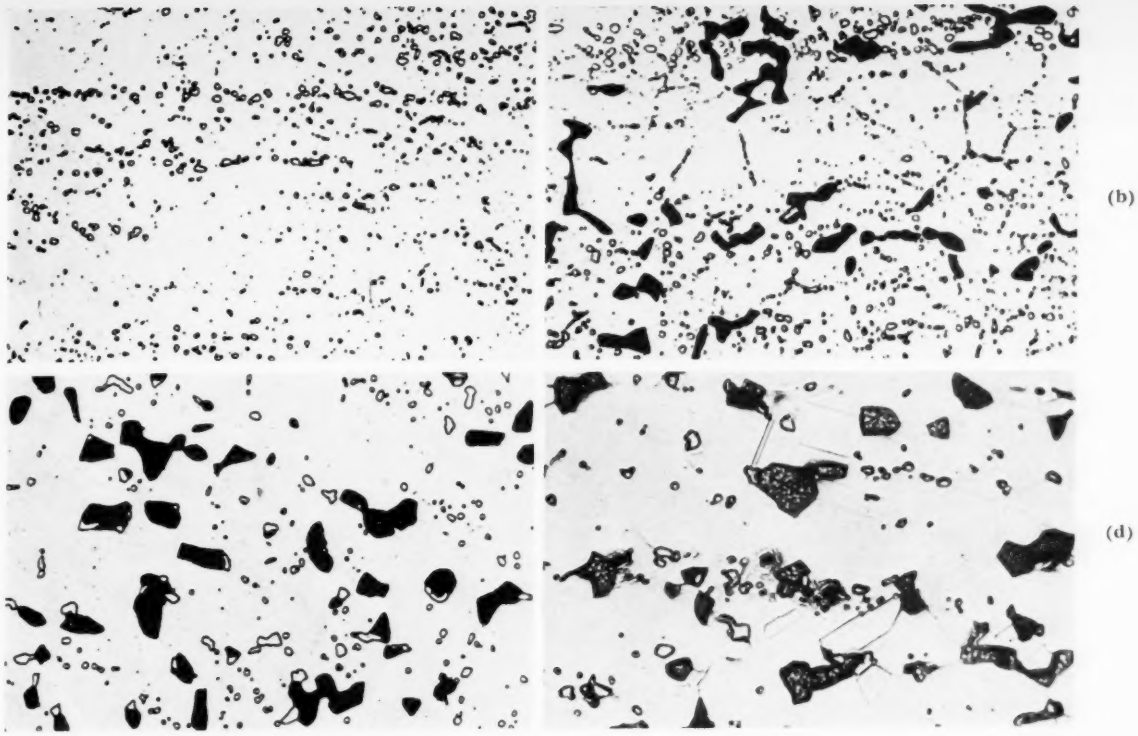

Fig. 3—Microstructure of steel *A* as annealed and after heating at 800° C. for 200-8000 hr. Sigma pitted by *aqua regia* etch. (*a*) Annealed (1050° C., A.C.); (*b*) as (*a*) + 200 hr. heating; (*c*) as (*a*) + 1000 hr. heating; (*d*) as (*a*) + 8000 hr. heating. × 500

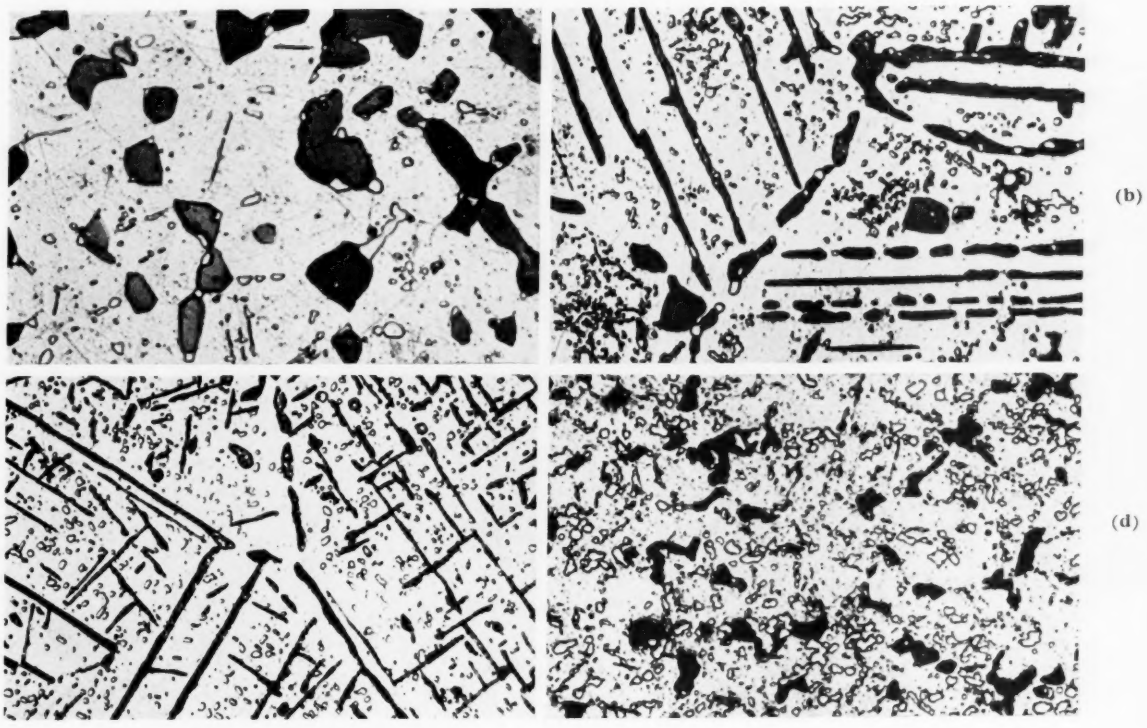

Fig. 4—Effect of annealing on distribution of sigma
(*a*) steel *B*: A.C., 1050° C. + 8000 hr. at 800° C. A.S.T.M. grain size 8.
(*b*) steel *B*: A.C., 1150° C. + 8000 hr. at 800° C. A.S.T.M. grain size 4.
(*c*) steel *C*: A.C., 1150° C. + 8000 hr. at 800° C. A.S.T.M. grain size 2.
(*d*) steel *D*: A.C., 1150° C. + 1000 hr. at 800° C. A.S.T.M. grain size 7.
Etched for 2 min. in *aqua regia* × 500

[*Morley and Kirkby*
[*To face p.* 132

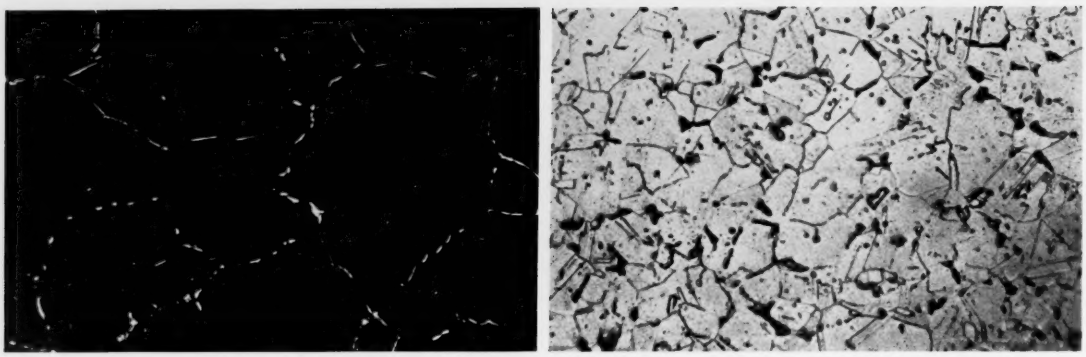

Fig. 5—Grain-boundary distribution of sigma in steel *A* : (*a*) 1150° C., A.C. + 1000 hr. at 800° C. Etched in potassium iodide/citric acid reagent. Austenite black, sigma white. (*b*) 1050° C., A.C. + 200 hr. at 800° C. Etched in *aqua regia*. Austenite white, sigma black (*a*) × 200 ; (*b*) × 300

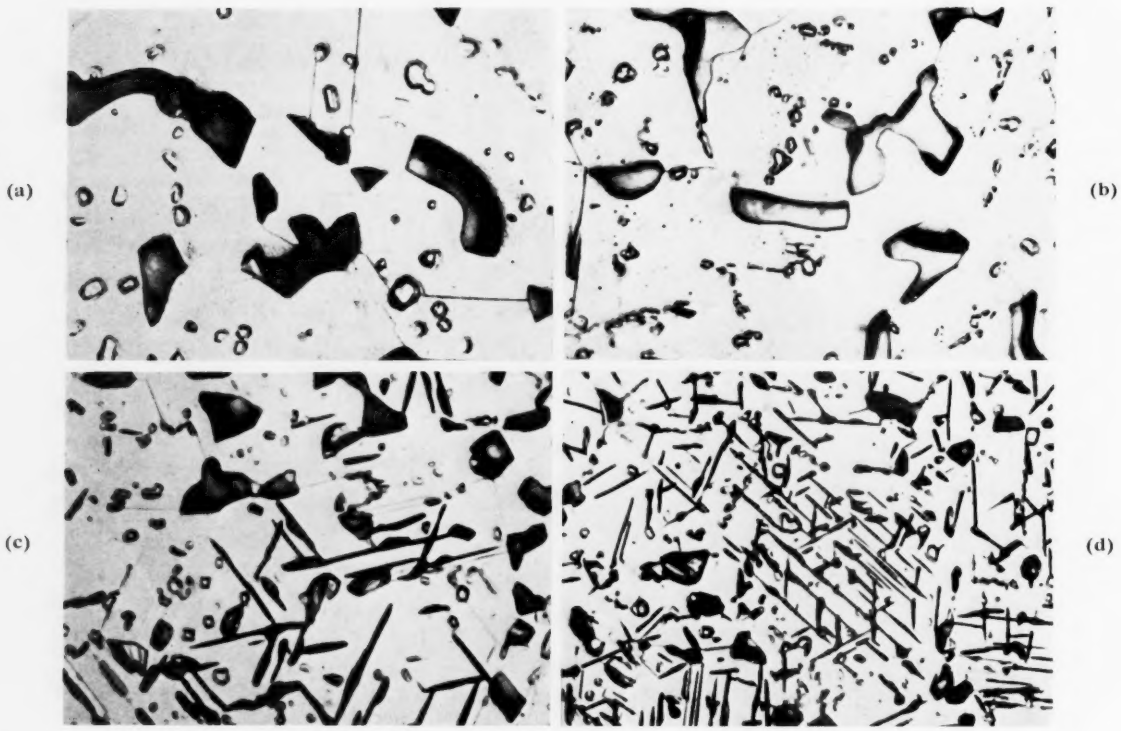

Fig. 6—Effect of temperature on distribution of sigma in steel *C*. A.C., 1050° C. + 1000 hr. at (*a*) 850° C. ; (*b*) 800° C. ; (*c*) 750° C. ; (*d*) 700° C. Electrolytically polished in electrolyte of perchloric acid/methyl alcohol and etched for 2 min. in *aqua regia* × 1500

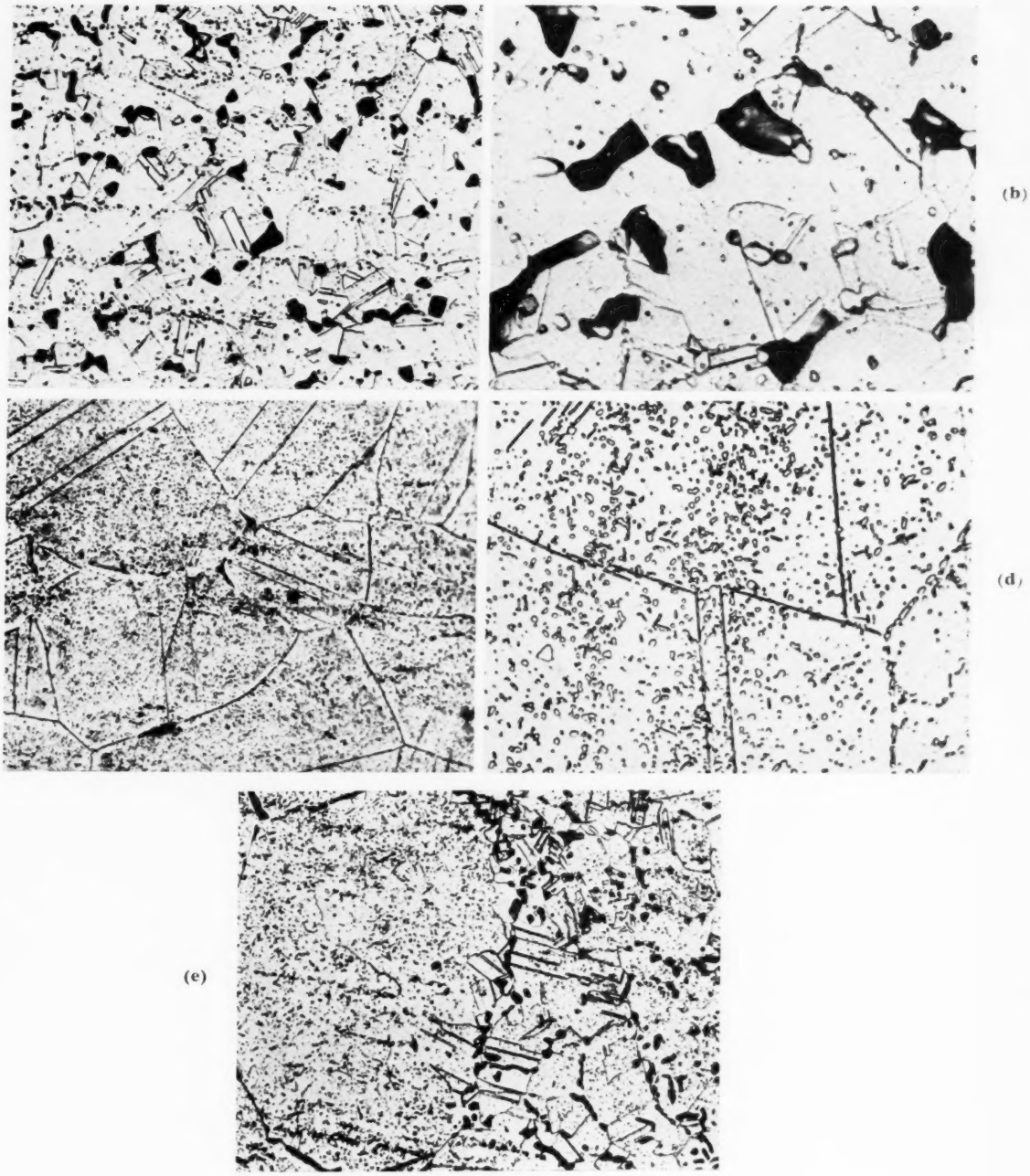

Fig. 7—Induction period for sigma in coarse-grained steel *A*.

(*a*) 1050° C., A.C. + 500 hr. at 800° C. ; 9% of σ (black) × 200
(*b*) As (*a*) $\gamma + \sigma$ + chromium carbides. Carbides undissolved in 1050° C. anneal. × 1000
(*c*) 1250° C., A.C. + 500 hr. at 800° C. Trace of σ (black) × 200
(*d*) As (*c*) γ + chromium carbides. Carbide precipitation at 800° C. × 1000
(*e*) 1250° C., A.C. + 1000 hr. at 800 °C. Shows recrystallization and more rapid σ precipitation induced by local prior cold-work. Brinell impression × 200

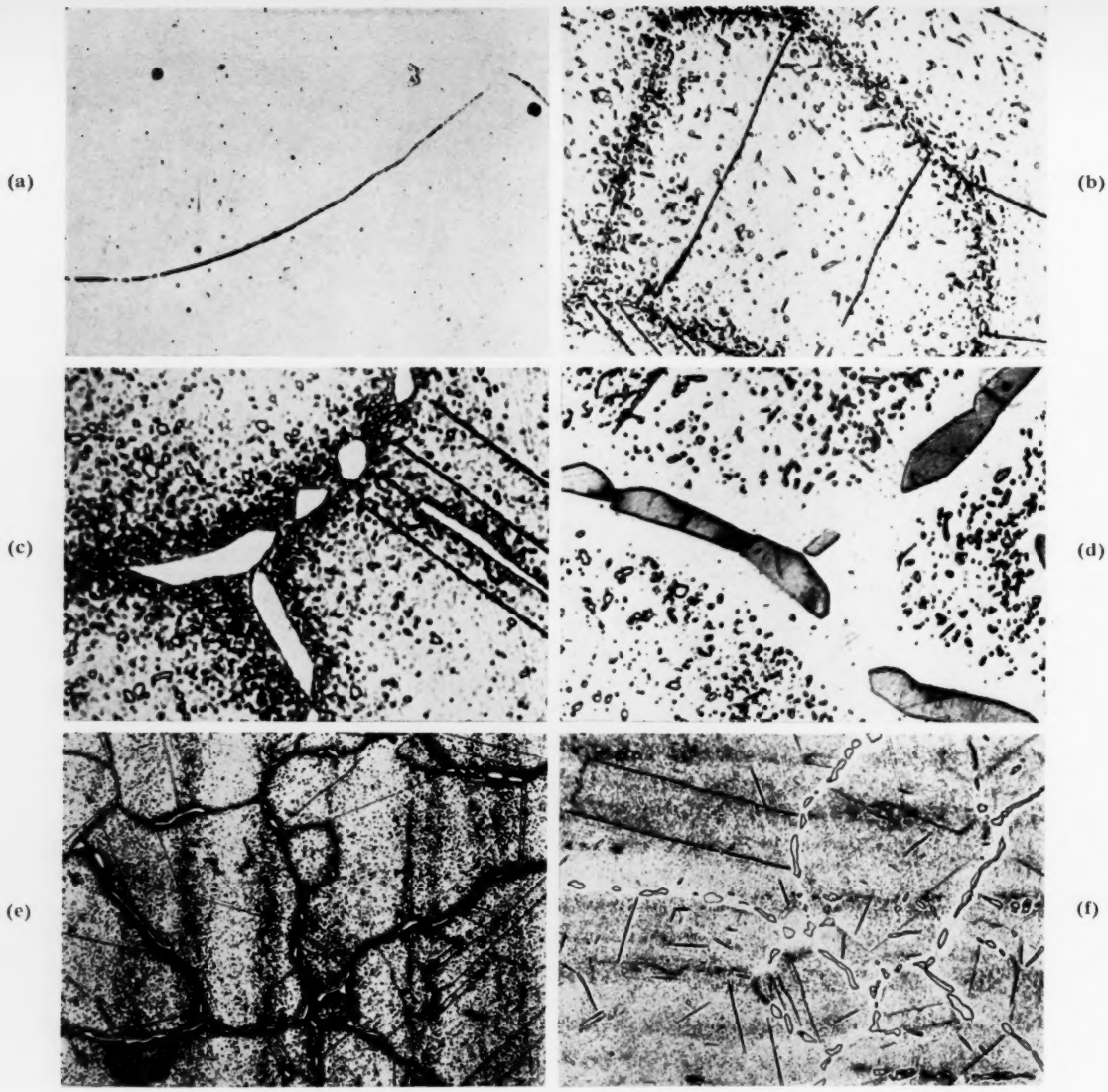

Fig. 8—Replacement of chromium carbides by sigma in coarse-grained steel *A*. (*a*) 1150° C., A.C. only ; (*b*) + 24 hr. at 800° C., γ + carbides; (*c*) and (*e*) + 500 hr. at 800° C., $\gamma + \sigma$ + carbides; (*d*) and (*f*) + 1000 hr. at 800° C., γ + carbides + σ. Etched in Marbles' Reagent (σ and carbides not attacked)
a-d **× 1500 ; *e-f*** **× 200**

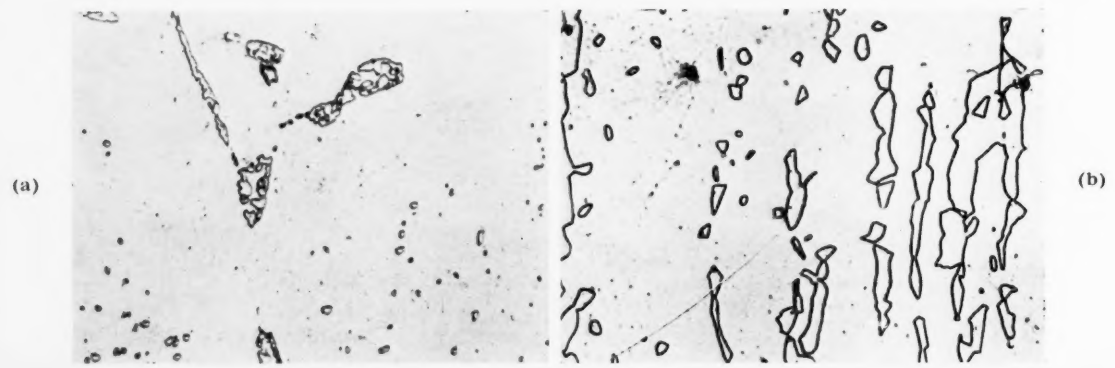

Fig. 9—Dissolution of sigma at 1050° C. : (*a*) 1150° C., A.C. + 1000 hr. at 800° C. (steel *A*) + 1 hr. at 1050° C. Showing σ replaced by carbides and new austenite (× 1000) ; (*b*) 1050° C., A.C. + 1000 hr. at 800° C. + 2 hr. at 1050° C. Ti-stabilized steel 24/19/Ti, showing σ replaced by metastable ferrite (× 500).

steels containing 1½% of Si indicates that the solubility for carbon varies with temperature, *i.e.*,

800° C.—0·04%	1150° C.—0·13%
1050° C.—0·06%	1250° C.—0·20%

Thus steel *B*, with 0·14% of carbon, needs treatment at 1150–1200° C. to dissolve the carbide completely, whereas steel *C*, with only 0·08% of carbon, will be free from carbide after rapid cooling from 1100° C.

The carbides visible in Fig. 3*a* (0·12% carbon steel) were undissolved in the initial treatment at 1050° C. Subsequent treatment at 800° C. produced very little additional carbide precipitation, but softening at 1150° C. dissolved the carbides (*see* Fig. 8*a*). They were then reprecipitated in the early stages of subsequent heating at 800° C. (*see* Fig. 8*b*). X-ray diffraction examination confirmed that the undissolved carbides after 1050° C. softening were similar to those precipitated during 24 hr. at 800° C. in a specimen originally softened at 1150° C. Both were of the type $(Cr,Fe)_{23}C_6$.

Table III and Fig. 7*c* show that about 500 hr. at 800° C. were required for the first appearance of σ in the coarsest-grained specimens of steel *A*. A similar treatment on the corresponding fine-grained specimens produced almost the equilibrium σ content. Prior cold work, however, accelerated the rate of σ precipitation in the coarse-grained steel (*see* Fig. 7*e*). The chromium carbides, which precipitated at 800° C. in the coarsest-grained specimens, but only to a very small extent in the fine-grained specimens, are shown in Fig. 7*d*.

Not only was the rate of sigma formation diminished in steels *A* and *B* at 800° C. by high-temperature solution treatments, but there was also a longer period before σ could be detected. No σ was detected in the 1150° C. annealed specimens of *A* and *B* during the first 72 hr. of heating at 800° C., but marked carbide precipitation occurred. Conversely, where there was little carbide precipitated at 800° C., as in the 1050° C. annealed specimens, σ was first detected after only 24 hr. at 800° C. In these steels, about 0·09% of carbon is free to precipitate at 800° C. after 1150° C. annealing, but only 0·02% after a 1050° C. anneal. Steel *C*, however, with the lowest carbon content, dissolved little more carbide at 1150° C. than

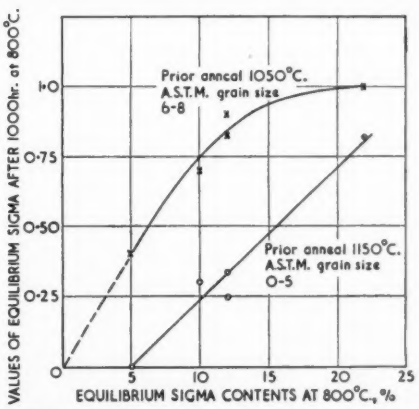

Fig. 10—Rate of sigma formation at 800° C. in titanium-treated steels with varying sigma contents (23–25% Cr—19–28% Ni)

at 1050° C. In this case, annealing at 1150° C. had no effect on the rate of σ formation.

This tendency for chromium carbides to precipitate before the σ might be explained in terms of the relative rates of diffusion of carbon and chromium in austenite at 800° C., the greater mobility of the carbon atoms being such as to involve much of the initial diffusion of chromium in precipitating chromium carbide. When the free carbon is exhausted, or nearly so, further diffusion of chromium in the still unstable austenite of the 25 Cr–20 Ni steel will precipitate σ.

This is not necessarily the sole explanation for the sluggish formation of σ in solution-treated steels, for about 500 hr. at 800° C. are required in the 1250° C. treated specimen of steel *A* for the first signs of σ, but only about 170 hr. in the corresponding 1150° C. specimen. Yet in this steel with only 0·12% of carbon, no more carbide is dissolved at 1250° C. than at 1150° C. Furthermore, σ forms more slowly in solution-treated specimens of steels *A* and *B* than can be accounted for in terms of the apparent induction periods (*see* Table III).

Besides grain size, the degree of supersaturation of the austenite with chromium must be considered as well as carbon content. Thus, in Table III, the coarsest

Table III

EFFECT OF SOFTENING TEMPERATURE ON SIGMA FORMATION

Steel	C, %	Si, %	Mn, %	Ni, %	Cr, %	Softening Treatment	A.S.T.M. Grain Size	Time at 800° C., hr., for: 0·05 Stable σ Content	Time at 800° C., hr., for: 0·50 Stable σ Content	Stable σ Content, %*
A	0·12	1·46	0·79	21·0	24·2	1050° C.	7, 8	24	170	10
						1150° C.	2, 3	170	1000	
						1250° C.	−1, 1	500	1900	
B	0·14	1·3	0·60	20·9	25·0	1050° C.	7, 8	24	400	14
						1150° C.	3, 5	100	700	
C	0·08	1·77	0·85	21·0	24·5	1050° C.	7	24	350	20
						1150° C.	1, 2	24	350	
						1250° C.	−1, 0	50	550	

* Stable σ content is the amount present in the fine-grained steel after stabilization at 800° C.

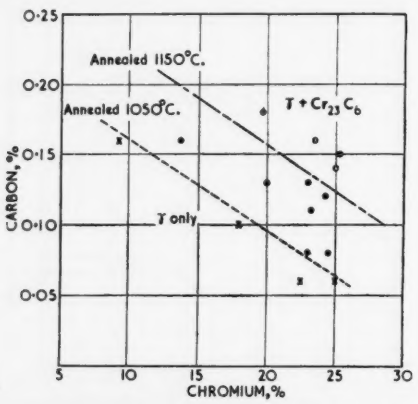

Fig. 11—Relationship between carbide solubility and chromium content in alloys containing Cr, Fe, 20% of Ni, and 1·5% of Si

grain size and lowest stable σ content (*i.e.*, lowest degree of supersaturation) are associated with the slowest rate of σ precipitation at 800° C. In steel *C*, however, the effect of coarse grain size is reduced by high supersaturation of Cr in austenite at 800° C.

The connection between the rate of σ formation and the degree of supersaturation of chromium in austenite at 800° C., as indicated by the stable σ content, is more clearly revealed by the titanium-treated steels. Thus, Fig. 10 indicates:

(i) That steels of this type, having high potential σ contents, form σ more rapidly than those which, because of their lower Cr and higher Ni contents, have smaller σ contents, and

(ii) That the rate of precipitation for any given σ content between 5–20% is retarded by prior annealing treatments that result in grain coarsening.

These steels were fully Ti-stabilized in the ratio of 4·7/8·2 times the carbon content, so that the slower rate of σ formation at 800° C. observed in the coarse-grained specimens cannot be attributed to carbide precipitation. Micro-examination confirmed that little precipitation, other than that of σ, occurred.

It appears to be less difficult to nucleate precipitates of σ inside the grains when the Cr supersaturation is high than when it is low. Thus, grain growth has little effect on the rate of precipitation in steels forming 20% or more of σ, but in steels forming only about 5% of this phase, the virtual restriction of σ nucleation to grain-boundary sites means that diffusion must take place over much longer periods to stabilize coarse-grained specimens.

Contribution of Carbide Precipitation to Embrittlement

The tests whose results are shown in Table IV were carried out on specimens heated at 800° C., so that grain-boundary carbides were present but no σ could be detected.

These confirmed that the grain-boundary carbides caused no serious embrittlement with A.S.T.M. grain sizes of 3–5, although they halved the impact resistance. They support the view that the form and distribution of σ contribute most to the loss of ductility suffered by the 25/20 bar steels.

METASTABLE CONSTITUENTS OF 25/20 STEELS

Carbide Precipitation at 800° C.

The chromium carbide precipitation which precedes σ formation at 800° C. in specimens previously annealed at 1150° C. or 1250° C. occurs largely in the grain boundaries (*see* Fig. 8*b*). When σ appears, it is also found first in the grain boundaries, where there is already much carbide precipitation (*see* Figs. 8*c* and *e*).

Longer periods of heating at 800° C., as shown by Figs. 8*d* and *f*, result in further growth of the grain-boundary σ particles and, surprisingly, in the disappearance of carbide precipitates at and near the grain boundaries. However, many of those carbides remain that were precipitated inside the grains on first heating at 800° C. Those shown in Fig. 8*d* are probably the stable carbides, since up to 2000 hr. at 800° C. no further change is detected, other than the continued slow growth of the σ precipitates.

It is suggested that the carbides that disappear from the grain boundaries at the beginning of σ formation are redissolved in the parent austenite grains; the chromium formerly combined with carbon, becoming available for the continued formation of σ. Presumably, the carbides dissolve when σ first appears in the vicinity, because the surrounding austenite is further depleted in chromium by the precipitation of σ and can then dissolve more carbon at the same temperature. Figure 11 shows that the solubility of austenite for carbon is a function of its chromium

Table IV

EFFECT OF CARBIDE PRECIPITATION IN STEELS *B* AND 19/20

Steel	C, %	Si, %	Cr, %	Ni, %	Heat-Treatment	A.S.T.M. Grain Size	0·5% Proof Stress (Tons/sq. in.)	U.T.S. (Tons/sq. in.)	Elong., %	Red. in A., %	Izod, ft. lb.	Microstructure
B	0·14	1·3	25·0	20·9	1150° C., A.C.	3–5	18·6	42·8	58	65	120	γ only
					1150° C., A.C. + 24 hr. 800° C.	,,	22·5	45·7	44	51	55	γ + carbides (*see* Fig. 8*b*)
19/20	0·18	1·8	19·4	20·2	1150° C., A.C.	3–5	18·7	40·6	57	67	120	γ only
					1150° C., A.C. + 200 hr. 800° C.	,,	17·8	40·4	42	47	41	γ + carbides

content: *e.g.*, a steel with 10% of Cr, 20% of Ni and 1·5% of Si, appears to dissolve about 0·17% of carbon at 1050° C., but in the 25% Cr–20% Ni–1·5% Si steel, the corresponding solubility is probably only 0·06%.

The over-precipitation of carbides at 800° C. probably indicates an indirect approach to equilibrium, the metastable carbides arising from the difference in the rates of diffusion of carbon and chromium in austenite at 800° C. The precipitation of chromium carbides is perhaps the quickest way in which the steel can move towards equilibrium at 800° C., but is not adequate in itself to give stability in terms of chromium dissolved in austenite. Therefore, σ also precipitates and the austenite, further depleted in chromium, can dissolve some of the initially formed carbides at the same temperature. Hence, the carbon content of the austenite appears to decrease rapidly to the metastable saturation value, and then increases slightly, but its chromium content falls progressively, although more slowly, until equilibrium is reached.

There is no metallographic evidence of this phenomenon in specimens initially softened at 1050° C., but in this case only small amounts of carbide are precipitated at 800° C., so that if it occurred it would be difficult to detect.

Ferrite at 1050° C.

When specimens of steel *A* containing σ are reheated at 1050° C., the σ disappears and is replaced by chromium carbides and new austenite (*see* Figs. 8*d* and 9*a*).

The new carbides probably represent at least 20 wt.-% of the σ originally present, so that if the precipitated carbon had previously been dissolved in the σ, it would indicate that σ can dissolve at least 1% of carbon at 800° C.

It is more likely that carbon diffuses from the austenite to precipitate chromium carbide at the σ boundaries, the ensuing reduction of chromium content causing a local transformation to austenite. It appears from Fig. 9*a* that the new carbide precipitates are found at the fringes of the original σ grains, now replaced by new austenite, as would be expected if carbon diffused from the parent austenite.

A Sigma Alloy

To investigate whether carbon dissolves appreciably in σ, a small cast was made to the composition indicated by chemical analysis of a σ residue,* which was: 0·37% of C; 2·67% of Si; 0·63% of Mn; 9·39% of Ni; 45·94% of Cr; 39·48% of Fe. Assuming all the carbon to be present as chromium carbide, the composition indicated for the σ and the analysis of a small cast made to represent it, are:

	C, %	Si, %	Mn, %	Ni, %	Cr, %	Fe, %
σ Composition	0	2·81	0·67	9·96	42·18	41·86
Special Cast	0·05	2·54	0·73	10·13	41·60	balance

On cooling from the casting temperature, the ingot fractured spontaneously. It was found to be mainly σ at room temperature with small amounts of carbide in eutectic form. Small pieces W.Q. from 1150° C. or 1250° C. consisted of ferrite and carbides. Sigma, ferrite, and carbide were present after water-quenching from 1050° C. Small samples were forged successfully at about 1250° C. and after water-quenching from this temperature could be machined fairly readily. Various experimental heat-treatments were carried out on both forged and cast specimens, but there was no evidence of any appreciable carbide solubility in the sigma.

These experiments also showed that the σ alloy began to transform to ferrite at 1050° C., but the σ precipitates in the 25/20 steel were replaced by austenite and carbides at 1050° C. To test the hypothesis that the carbides so formed are the result of carbon diffusion from the surrounding austenite, steels with and without titanium (*i.e.*, *B*, *C*, and 24/19/Ti) were examined after various heat-treatments; the composition of the latter was: 0·07% of C; 1·13% of Si; 1·28% of Mn; 19·5% of Ni; 24·4% of Cr; 0·49% of Ti. All specimens were heated at 800° C., to produce substantial quantities of σ, and then reheated (*see* Table V).

Ferrite is present in place of σ in all three steels immediately after heating to 1150° C., but rapidly transforms to austenite in those with free carbon (*i.e.*, not Ti-stabilized) if they are soaked at 1050° C.

The relative sluggishness of the metastable ferrite in the Ti-stabilized steel 24/19/Ti suggests that its transformation back to austenite depends on the diffusion of Cr and Ni into and from the present austenite. On the other hand, when free carbon is present, as in steels *B* and *C*, it moves rapidly into the high-chromium ferrite zones vacated by σ and precipitates chromium carbide at the interface, thus facilitating the transformation to stable austenite.

These observations are consistent with the work of Schafmeister and Ergang,[5] who pointed out that σ can dissolve up to 10% of Ni, and also with those of Dulis and Smith,[10] who found σ transforming to metastable ferrite in an 18/12/Mo steel.

Although the authors have evidence that the σ in the fully austenitic 25/20 steels does not transform directly to austenite when heated at temperatures over its stable range, but does so through the medium

* Extracted by anodic treatment in a solution of potassium iodide and citric acid.

Table V

EFFECT OF REDISSOLVING THE SIGMA PHASE IN STEELS *B*, *C*, AND 24/19/Ti

Heat-Treatment	Constituents Replacing σ		
	Steel *B*	Steel *C*	Steel 24/19/Ti
Wafer specimen flash-heated to 1150° C. approx.	Mainly α	Mainly α	Mainly α
15 min. 1050° C., W.Q.	$\alpha + \gamma + Cr_{23}C_6$	$\alpha + \gamma + Cr_{23}C_6$	Mainly α
30 min. ,, ,,	$\gamma + Cr_{23}C_6$	$\gamma + Cr_{23}C_6$	...
2 hr. ,, ,,	$\gamma + Cr_{23}C_6$	$\gamma + Cr_{23}C_6$	$\alpha + \gamma$
6 hr. ,, ,,	...	...	$\alpha + \gamma$
16 hr. ,, ,,	...	...	γ only

Table VI

EFFECT OF PRIOR COLD WORK ON SIGMA FORMATION

C, %	Si, %	Mn, %	S, %	P, %	Cr, %	Ni, %
0·08	1·77	0·85	0·004	0·020	24·5	21·0

Heat-Treatment	Prior Cold Work, %		
	0	5	40
	Sigma, %*		
Time at 700° C., hr.			
24	0	0	1
200	4	2	5
700	10	9	18
8000	30	30	30
Time at 750° C., hr.			
24	1	0	3
200	5	8	16
700	12	13	18
8000	25	24	21
Time at 800° C., hr.			
24	2	3	11
200	7	7	15
700	14	15	20
8000	22	...	20
Time at 850° C., hr.			
24	2	2	10
200	5	4	12
700	9	8	12
8000	13	10	11

* The estimates of vol.-% of σ were obtained by point counting and by comparison with standards, and are considered to be accurate to ± 1 part in 5

of a metastable ferrite, they have none to suggest the occurrence of an intermediate ferrite when σ precipitates from austenite at lower temperatures. Such observations have been made by Rees, Burns, and Cook[4] for a pure alloy containing 23% of Cr, 17% of Ni, and the balance iron. Suspecting that this apparent discrepancy might arise from the presence of carbon in the commercial steels, particular attention was given to the Ti-stabilized steels, but an X-ray diffraction technique of 1% sensitivity failed to reveal the presence of ferrite in specimens heated for varying periods at 800° C.

EFFECT OF COLD WORK ON THE PRECIPITATION OF SIGMA

During an investigation dealing with the recrystallization characteristics of this alloy, using a cold-working and reheating technique on solid specimens, it was observed that cold work before exposure accelerated the rate of σ formation. Although generally consistent with published results, the effect is much less marked than that obtained by Rees, Burns, and Cook, who suggested a factor of 6000 at 650° C.[4] Their high assessment may be the result of comparing cold-worked specimens with extremely coarse-grained cast sections homogenized at 1350° C., in which, as the present paper suggests, σ formation may be abnormally sluggish.

Specimens of ¾-in. dia. bar, initially A.C. at 1050° C., were cold-worked by stretching 5%, 10%, 20%, and 40% in a tensile machine, after which they were reheated in the range 700–850° C. for periods of 24–8000 hr. The specimens were finally examined microscopically, and the summarized results are given in Table VI. These results fully confirmed the earlier experiences in regard to the accelerating influence of initial cold work on σ formation, but it will be noted that large deformations are required. This method was also used as an accelerated test in alloys of varying compositions.

EFFECT OF MODIFIED COMPOSITION ON THE MICROSTRUCTURES OF 25Cr–20Ni STEEL

The effect of modified composition on the amount of sigma formed was investigated, to find a steel of the 25/20 type that would be relatively free from σ under any circumstance.

A series of experimental steels was produced in bar form and softened by air-cooling from 1050° C. Advantage was taken of the accelerating effect of prior cold work on the precipitation of σ, to facilitate comparison of the various steels under equilibrium or near-equilibrium conditions in a reasonably short time. Small cylindrical specimens cut from the bars were severely deformed in compression after softening, the applied load being sufficient to cause a permanent 50% reduction in length. The compressed specimens were then heated for 700 hr. in the range 700–850° C., and used for micro-examination.

The evidence in Table VI indicates that 700 hr. heating at 700–850° C. of a heavily cold-worked sample, originally softened at 1050° C., is adequate to achieve a good measure of stability in regard to the amount of σ formed. Although equilibrium is probably reached in a heavily cold-worked specimen after 700 hr. at 850° C. or even 750° C., Table VI indicates that longer periods of heating are required at 700° C. The results given in Table VII should not, therefore, be taken as equilibrium σ contents at 700° C.

The steels used covered the following ranges of composition: 0·05–0·25% of C; 0·20–2·70% of Si; 0·70–1·50% of Mn; 19·40–25·0% of Cr; 20·20–28·60% of Ni; 0–0·46% of Ti; and 0–1·60% of Nb.

A reasonable assessment of the contributions of

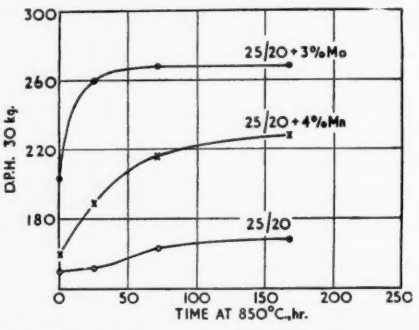

Fig. 12—Effect of manganese and molybdenum on the sigma hardening of 25/20 bar steel (850° C. hardening treatment preceded by 1 hr. at 1050° C., A.C.)

individual alloy elements to σ formation is obtained by taking account of the major variations of these elements, although in some ca es there are reservations due to incidental variations of composition (*see* Table VII).

Silicon

Steel 3*S* (Table VII) shows that a reduction of Si content in an otherwise normal composition reduces σ formation, a feature that is particularly marked at 850° C. (steel 1*S*).

Silicon appears to extend the range of existence of σ to higher temperatures. In a separate experiment, specimens containing large amounts of σ were heated at 900–1000° C. for 64 hr. Results were:

Steel	As-received	Sigma Phase, % As-received + 64 hr. at 900° C.	As-received + 64 hr. at 950° C.	As-received + 64 hr. at 1000° C.
3*S* (2·7% Si)	15	5–10	5	0
2*S* (1·6% Si)	10	5	0	0
1*S* (0·6% Si)	5–10	0	0	0

As-received = 1050° C., A.C., + 2000 hr. at 800° C.

The specimen of 3*S* treated at 950° C. was heated for a further 48 hr. at the same temperature without any significant change in the amount of σ present. Thus, σ appears to be a stable phase at temperatures at least as high as 950° C. in the presence of about 2·5% of Si, but a 2% reduction of Si content depresses the upper limit by about 100° C. This is consistent with the results of other investigators.

Chromium

To reduce substantially the percentage of σ formed with the normal 1·5% silicon material, the chromium content must be reduced to about 20% (steels 24/20 to 19/20). Notwithstanding the lower Si content of the Ti-stabilized 24/20/Ti to 21/20/Ti steels, substantial amounts of σ were found with a Cr content of 21%. A Cr content below 18% would be necessary to eliminate the formation of σ in the presence of titanium. In a Ti-stabilized steel having 28% of Ni, a reduction of the Cr content to 20% virtually eliminated σ at 700° C. and above (steel 20/28/Ti).

Nickel

In all cases, increasing the nickel content to about

Table VII

EFFECT OF MODIFIED COMPOSITION ON SIGMA FORMATION

Steel No.	Principal Elements Varied	C, %	Si, %	Mn, %	Cr, %	Ni, %	Ti, %	Nb, %	N_2, %	Estimated Sigma, vol.-% 700° C.	750° C.	800° C.	850° C.
3 *S*	Si	0·18	2·7	1·1	24·1	21·0	...	...	...	15	15	13	15
2 *S*	,,	0·16	1·6	1·0	24·4	21·9	...	...	...	10	10	11	6
1 *S*	,,	0·13	0·56	0·8	24·7	21·0	...	...	...	8	8	8	2
24/20	Cr	0·16	1·6	1·0	24·4	21·9	...	...	...	10	10	11	6
23/20	,,	0·13	1·5	0·7	22·9	21·1	...	...	...	6	7	7	3
19/20	,,	0·18	1·8	0·8	19·4	20·2	...	...	...	4	0	0	0
24/20/Ti	Cr (+ Ti)	0·07	1·13	1·3	24·4	19·3	0·49	...	...	23	23	22	15
23/20/Ti	,,	0·07	1·06	1·4	22·5	19·7	0·57	...	...	20	17	15	10
21/20/Ti	,,	0·09	1·13	1·5	21·1	19·9	0·53	...	...	14	11	10	10
24/28/Ti	Cr (28 Ni + Ti)	0·05	0·87	1·3	24·5	28·5	0·40	...	...	11	10	12	8
23/28/Ti	,,	0·06	0·64	1·4	23·0	28·6	0·40	...	...	8	8	5	0
20/28/Ti	,,	0·06	0·48	1·4	20·0	27·8	0·28	...	...	0	0	0	0
24/21	Ni (Low Si)	0·13	0·56	0·8	24·7	21·0	...	...	...	8	8	8	2
24/24	,,	0·16	0·70	0·8	23·7	24·2	...	...	...	5	5	6	2
24/26	,,	0·16	0·20	1·2	24·1	26·4	...	...	...	7	5	4	0
24/28	,,	0·16	0·73	1·5	24·0	28·2	...	...	...	0	0	0	0
24/19/Ti	Ni (24 Cr + Ti)	0·07	1·13	1·3	24·4	19·3	0·49	...	...	23	23	22	15
24/28/Ti	,,	0·05	0·87	1·3	24·5	28·5	0·40	...	...	11	10	12	8
23/20/Ti	Ni (23 Cr + Ti)	0·06	1·06	1·4	22·5	19·7	0·57	...	...	20	17	15	10
23/28/Ti	,,	0·06	0·64	1·4	23·0	28·6	0·40	...	...	8	8	5	0
1 *M*	Mn	0·08	1·8	0·80	24·5	21·0	...	...	...	18	18	20	12
4 *M*	,,	0·11	1·8	3·9	24·8	20·7	...	...	...	35	30	25	24
LN 2	N_2	0·13	1·5	0·70	22·9	21·1	...	...	0·045	6	7	7	3
HN 2	,,	0·11	1·5	0·70	23·2	21·1	...	...	0·17	1	4	0	0
HC 1	C	0·16	1·6	1·0	24·4	21·9	...	...	...	10	10	11	6
HC 2	,,	0·21	2·2	0·8	24·8	21·0	...	...	...	15	15	15	10
LC 1	,,	0·08	1·8	0·8	24·5	21·0	...	...	...	18	18	20	12
LC 2	,,	0·06	2·0	0·8	25·0	21·1	...	...	...	20	20	20	18
HC	C (Low Cr)	0·25	1·4	0·8	22·7	21·2	...	...	...	5	5	3	0
MC	,,	0·13	1·5	0·7	22·9	21·1	...	...	...	6	7	7	3
LC	,,	0·08	1·5	0·8	22·9	21·2	...	...	...	...	11	12	8
0*T*	Ti	0·08	1·8	0·8	24·5	21·0	...	...	...	18	18	20	12
24/20/Ti	,,	0·07	1·1	1·3	24·4	19·5	0·49	...	...	23	23	22	15
0*T*28	Ti (High Ni)	0·09	0·68	1·1	24·2	28·6	...	...	...	6	7	4	0
24/28/Ti	,,	0·05	0·90	1·3	24·5	28·5	0·41	...	...	11	10	12	8
0*NB*	Nb (23 Cr)	0·13	1·5	0·70	22·9	21·1	...	...	...	6	7	7	3
24/20/Nb	,,	0·13	1·2	0·70	23·6	21·5	...	1·5	...	16	15	15	9
0*NB*28	Nb (High Ni)	0·16	0·73	1·5	24·0	28·2	...	...	...	0	0	0	0
24/28/Nb	,,	0·18	0·80	1·5	24·6	28·4	...	1·6	...	9	10	8	2

28% had a significant effect in reducing the formation of sigma. The constituent can be virtually eliminated in a titanium-free material with 23–24% of Cr and low Si, provided that about 0·15% of carbon is present (steel 24/28).

Manganese

Steel 4*M* suggests that 4% of manganese caused an appreciable increase in the amount of σ formed.

Similar experiments on material without the initial cold work showed that σ formed more rapidly in the presence of 4% of Mn than in any other austenitic steel of the 25/20 type investigated, with the exception of one containing 3% of molybdenum, which was also free from ferrite. The hardening produced in these steels by σ precipitation at 850° C. is shown in Fig. 12.

Nitrogen

Small additions of this element reduced σ formation to about the same extent as an equal amount of carbon (steel *HN*2). This does not confirm the results given by Payson and Savage[6] in regard to nitrogen additions.

Carbon

Broadly, as the carbon content is lowered, the amount of σ formed is increased. This trend would be expected, since an increase of carbon will automatically increase the amount of chromium carbide formed at 700–850° C. This, in turn, will effectively lower the Cr content of the matrix and reduce the σ-forming propensities of the material. Payson and Savage[6] come to the same conclusion.

Since the carbide is known to be of the type $(Cr,Fe)_{23}C_6$, and the solubility of this carbide in the 25/20 steel is about 0·04% of carbon at 800° C., it is possible to calculate how much Cr is combined with undissolved carbide. Thus in steel *HC*1 with 0·16% of carbon, 1·65% of Cr will be present as carbide after stabilizing at 800° C., but only 0·64% of Cr will be so combined in the 0·08% carbon steel *LC*1. These estimates assume no replacement of Cr in the carbide with iron, but if about 30% replacement occurs, the corresponding figures will be 1·15% and 0·46% of Cr respectively.

A clear indication of the effect of carbon is given by steels *HC*, *MC*, and *LC*, with 0·25, 0·13, and 0·08% of carbon respectively. Sigma formation can be halved in this range of carbon content. Moreover, the combined effect of lower Cr (22·8%) and higher carbon (0·25%), as in *HC*, is such that σ can be eliminated at 850° C., although not at lower temperatures.

Titanium

As might be expected, the addition of titanium increased the amount of σ formed, since Ti has the effect of reducing the carbon content of the material. The differences were small, because of the low carbon contents of the Ti-free casts 0*T* and 0*T*28.

Niobium

Steel 24/28/Nb, containing about nine times more niobium than carbon, produced 8 or 10% of σ at 700° and 800° C., but a very similar cast 0*NB*28, without Nb, was free from sigma. Since, in this case, little, if any, more Nb was present than is needed to stabilize the carbon content, it appears that carbide stabilization is in itself a powerful stimulant and that it is not necessary to have any large excess of Nb to promote additional σ formation. This agrees with the observations already made on the effect of low carbon contents.

EFFECT OF MODIFIED COMPOSITION ON MECHANICAL PROPERTIES

Modified Steels Annealed at 1050° C.

Lower Chromium Content—The first modification to be tested was a 20% chromium steel in which σ does not form above 750° C. The tests, the results of which are given in Table VIII, were carried out at 800° C. Steel 19/20 had the following composition: 0·18% of C; 1·8% of Si; 0·8% of Mn; 19·4% of Cr; 20·2% of Ni.

The microstructures of this steel before and after heating at 800° C. showed only austenite and chromium carbides, many of which were undissolved in the initial softening treatment. The high ductility and impact resistance after 8000 hr. heating at 800° C. indicate the improvement to be expected from eliminating sigma.

Higher Nickel and Carbon Contents—Three steels, with potentially smaller amounts of σ than the standard 25% Cr–20% Ni steel, were examined. Details of these tests are given in Table IX.

The trend for reduced ductility in the steels as softened, according to carbon content, is probably explained by the increasing amounts of chromium carbide undissolved at 1050° C.

About 3–4% of σ formed in each of these steels during 8000 hr. heating at 800° C., the effect of higher carbon being offset presumably by the rather higher Cr contents of steels *E* and *F*. This amount of σ represents the stable structure of the steel at 800° C.

Compared with the tests on the standard 25/20 steel,

Table VIII

EFFECT OF LOWER Cr CONTENT ON PHYSICAL PROPERTIES

Heat-Treatment	0·5% Proof Stress (Tons/sq. in.)	U.T.S. (Tons/sq. in.)	Elong., %	Red. in Area, %	Izod, ft.lb.	Sigma, %
A.C. 1050° C.	20·9	43·5	51	64	120	Nil
" " + 1000 hr. 800° C.	19·4	41·0	48	56	91	Nil
" " + 8000 hr. 800° C.	16·1	38·5	46	57	90	Nil

reported in Table I, it appears that reducing the σ content from 10% to 4% slightly improved the room-temperature elongation after extended heating at 800° C. and considerably reduced the extent of Izod embrittlement. However, even 4% of σ precipitated in fine-grained steels is sufficient to cause some loss of impact resistance.

Effect of Added Titanium—In the previous section, it was shown that the addition of titanium to a standard 25/20 steel materially increased the amount of σ precipitated. Tensile tests were carried out on steels 24/20/Ti, 21/20/Ti, and one with 22·2% of Cr, 20·8% of Ni, and 0·54% of Ti. An attempt was made to compensate for the effect of Ti on σ formation by reducing chromium.

Though in a fine-grained condition, steel 24/20/Ti, with about 22% of σ after extended heating at 800° C., embrittled more than the standard 25% Cr–20% Ni steel.

Reducing the chromium content to 22% gave a considerable improvement, making the Ti-bearing steel roughly equivalent to the standard 25/20 steel in regard to the extent of embrittlement.

Sigma formed more slowly at 700° C. than at 800° C. and the rate of embrittlement was accordingly less. It also precipitated in an acicular form within the grains at 700° C., but this did not greatly influence the degree of embrittlement of the fine-grained steels.

Higher Nickel Content and Added Titanium—Tensile test data were also obtained on three steels having 28% of Ni and 0·30–0·40% of Ti in which the Cr content was reduced from 24·5 to 20%.

The 24/28/Ti steel, with 24·5% of Cr, embrittled to about the same extent as the standard 25% Cr–20% Ni steels as the result of heating at 800° C., and precipitated about the same quantity of σ, 10–12%. Thus it appeared that an increase of 8% of Ni had offset the effect of titanium.

The lower Cr content of steel 23/28/Ti reduced the σ content at 800° C. to about 5%. This small amount of second phase was associated with a reduction of Izod impact resistance to about 40 ft.lb. but had little effect on ductility in the tensile test.

The steel with 20% of Cr, 20/28/Ti, fully maintained its ductility and impact resistance after several months' heating at both 700° and 800° C. In this case no σ was formed.

These data allowed an assessment of the value of increased nickel in Ti-bearing steels. Whereas 24/28/Ti, with 28·5% of Ni and 24·5% of Cr, was not seriously embrittled by heating at 800° C., except as indicated by the Izod test, 24/20/Ti, with a similar Cr content but only 19·5% of Ni, suffered very severe embrittlement. Similarly, steel 23/28/Ti was better than the lower Ni steel 23/20/Ti.

Modified Steels Annealed at 1150° C.

The tests previously discussed were carried out on fine-grained material initially softened at 1050° C. To show the effect of σ in somewhat coarser-grained steels, such as might be encountered when dealing with thick plate material, similar tests were also undertaken after an initial treatment at 1150° C. and heating for long periods at 700° and 800° C.

Apart from a slight improvement in ductility arising from additional carbide solution, steels 0*T*28, *E*, and *F*, after an 1150° C. treatment and heating for 1000 and 8000 hr. at 800° C., gave results very similar to those reported in Table IX. After 8000 hr. at 800° C., similar amounts of σ had precipitated in both the 1050° and 1150° C. softened steels, and in both series it occurred only at isolated points in the grain boundaries. This similarity is evidently explained by the fact that the 1150° C. treatment failed to coarsen the grain, the largest A.S.T.M. grain size noted being that of the lower carbon steel 0*T*28, which after 1150° C. softening was only 5–6.

Table IX

28% NICKEL STEELS SOFTENED AT 1050° C.

	C, %	Si, %	Mn, %	Cr, %	Ni, %
0*T*28	0·09	0·68	1·1	24·2	28·6
E	0·15	0·68	1·1	25·0	28·8
F	0·26	0·78	1·2	25·2	28·5

Stable Sigma Contents at 800° C.

(½ hr. 1050° C., A.C. + cold work + 700 hr. 800° C.)

0*T*28	4
F	4

Steel	Heat-Treatment	0·5% Proof Stress (Tons/sq. in.)	U.T.S. (Tons/sq. in.)	Elong., %	Red. in Area, %	Izod, ft.lb.	A.S.T.M. Grain Size	Sigma, %	Distribution of Sigma
0*T*28	½ hr. 1050° C., A.C.	20·0	43·1	49	65	120	6–7	Nil	...
	,, ,, ,, + 1000 hr. 800° C.	20·6	42·0	41	51	53		1–2	B
	,, ,, ,, + 8000 hr. 800° C.	18·8	41·2	36	45	37		3–4	B
	,, ,, ,, + 8000 hr. 700° C.	18·6	41·0	33	39	20		5	B
E	½ hr. 1050° C., A.C.	24·0	46·7	41	56	94	6–7	Nil	...
	,, ,, ,, + 1000 hr. 800° C.	23·4	45·2	35	47	43		3	B
	,, ,, ,, + 8000 hr. 800° C.	22·4	44·3	37	45	41		4	B
	,, ,, ,, + 8000 hr. 700° C.	21·7	43·0	27	30	15		7	B
F	½ hr. 1050° C., A.C.	25·6	46·3	37	52	62	8	Nil	...
	,, ,, ,, + 1000 hr. 800° C.	24·5	45·3	34	44	33		2	B
	,, ,, ,, + 8000 hr. 800° C.	22·5	43·8	36	43	36		3	B
	,, ,, ,, + 8000 hr. 700° C.	23·4	44·3	27	32	12		8	B

B = Sigma precipitated in grain boundaries

Table X gives the results obtained on some titanium-bearing steels after 1150° C. softening and subsequent heating at 800° C. Steel 22/20/Ti contains about the same amount of σ as the standard 25/20 steel. Although the coarser grain size induced by 1150° C. treatment has resulted in somewhat greater loss of ductility than in corresponding specimens annealed at 1050° C., the steel is not very brittle. It is considered that the relative freedom from carbide precipitation resulting from the presence of Ti has contributed to the small improvement compared with coarse-grained Ti-free steels. Larger amounts of σ appear to obscure this effect of titanium.

Table X shows that annealing at 1150° C. appears to have little effect on 23/28/Ti, with a stable σ content of only 5%, although the rate of σ formation in this case is very slow. The σ-free steel 20/28/Ti, as would be expected, also remains ductile after extended heating at 800° C.

SUMMARY AND CONCLUSIONS

A typical bar steel, containing 0·10% of C, 1·5% of Si, 24% of Cr, and 20% of Ni, is fully austenitic at 1150° C., but will precipitate chromium carbides between 1100° and about 925° C., and chromium carbides plus σ if heated for long periods at lower temperatures.

The σ in this steel has been found to contain 42% of Cr, 10% of Ni, 3% of Si, and the remainder iron. Because considerable diffusion of Cr and Ni has to occur, long periods of heating are required for σ to precipitate from the austenite. At 800° C., at least 24 hr. will be required for the first trace to be detected in the grain boundaries, and at least 1000 hr. in a fine-grained steel for equilibrium to be established. At lower temperatures, σ forms even more slowly.

This behaviour contrasts with that of certain partially ferritic 18/8 molybdenum–titanium steels, where the higher concentrations of Cr and Mo in the ferrite than in the austenite at the annealing temperature may allow σ to precipitate during the air-cooling of plates and bars.

Sigma precipitates on relatively few nuclei, mainly in the grain boundaries of fine-grained 25/20 steels heated at about 800° C. Most of the grain-boundary area is free from precipitates. There is little hardening and at least 20% elongation may be shown by such steels in the presence of 15 vol.-% of sigma. In tensile tests, the σ particles fracture, but the cracks do not readily propagate. Izod impact resistance at room temperature is much reduced.

The amount of σ at any temperature can vary widely with small differences in steel composition; *e.g.*, variations of Cr and Si between 23–25% and 0·5–1·5% respectively may make a difference between stable σ contents of 5 and 20% at 800° C. Chromium, silicon, and, to a lesser extent, manganese are σ-promoting elements. Sigma-inhibiting elements are carbon, nitrogen, and nickel, the former because of their ability to reduce the effective chromium content. Nickel has only a mild effect. Carbide-stabilizing elements, *e.g.*, titanium and niobium, reduce the σ-inhibiting effect of carbon. Within the limits of composition investigated, no single variation seems capable of eliminating σ in the range 700–850° C. though the temperature range over which σ is stable is modified. Thus, the upper limit for σ formation can be reduced from about 975° C. with 2·7% of Si to about 875° C. with 0·6% of Si. Carbon up to 0·2% is only mildly effective, but with only 19·4% of chromium and 0·18% of carbon, σ does not form above about 725° C. In the case of Ni, work has not been carried out with 1·5% Si content, but it can be deduced that even 28% of Ni would be inadequate for this purpose.

Table X

TITANIUM-BEARING STEELS SOFTENED AT 1150° C.

	C, %	Si, %	Mn, %	Cr, %	Ni, %	Ti, %
22/20/Ti	0·09	0·9	1·4	22·2	20·8	0·54
24/28/Ti	0·05	0·9	1·3	24·5	28·5	0·41
23/28/Ti	0·06	0·6	1·4	23·0	28·6	0·40
20/28/Ti	0·06	0·5	1·4	20·0	27·8	0·28

Stable Sigma Content at 800° C.

(½ hr. 1050° C., A.C. + cold work + 700 hr. 800° C.)

22/20/Ti	12%	23/28/Ti	5%
24/28/Ti	12%	20/28/Ti	Nil

Steel	Heat-Treatment	0·5% Proof Stress (Tons/sq. in.)	U.T.S. (Tons/sq. in.)	Elong., %	Red. in Area, %	Izod, ft.lb.	A.S.T.M. Grain Size	Sigma, %	Distribution of Sigma
22/20/Ti	1 hr. 1150° C., A.C.	15·9	36·9	52	56	120	0–4	Nil	...
	,, ,, ,, + 1000 hr. 800° C.	17·1	37·3	38	39	25	,,	4	B
	,, ,, ,, + 6000 hr. 800° C.	17·5	37·8	22	17	7	,,	10	BA
24/28/Ti	1 hr. 1150° C., A.C.	16·3	37·1	50	67	120	1–4	Nil	...
	,, ,, ,, + 1000 hr. 800° C.	17·6	38·0	34	34	18	,,	3	B
	,, ,, ,, + 6000 hr. 800° C.	18·0	30·8	6	7	6	,,	12	BA
23/28/Ti	1 hr. 1150° C., A.C.	17·0	35·3	53	69	120	1–5	Nil	...
	,, ,, ,, + 1000 hr. 800° C.	19·5	36·5	45	62	120	,,	Nil	...
	,, ,, ,, + 6000 hr. 800° C.	16·5	35·6	44	48	...	,,	2–3	B
20/28/Ti	1 hr. 1150° C., A.C.	...	...	...	...	...	...	...	...
	,, ,, ,, + 1000 hr. 800° C.	16·7	36·3	43	55	110	1–6	Nil	...
	,, ,, ,, + 6000 hr. 800° C.	16·2	35·7	48	59	...	,,	Nil	...

BA = Sigma precipitated in grain boundaries and acicular within grains
B = Sigma precipitated in grain boundaries only

By combining two or more composition changes, σ can be completely suppressed at 700° C. and above without appreciably modifying the Cr content. Thus, 23–24% of Cr, 0·5–0·6% of Si, 28% of Ni, and 0·15% of carbon would be a suitable composition from this point of view, and would appear to be the only combination of elements to bear comparison with the normal 25/20 composition in terms of oxidation resistance.

The extent of room-temperature embrittlement is clearly related to the amount of σ present, although the relation depends on grain size. The different effects of the same amount of precipitate on the tensile elongation and Izod-impact resistance of fine- and coarse-grained steels after heating at 800° C. are shown in Table XI, the figures being derived from smoothed curves representing various casts of normal 25/20 steels and Ti-treated steels. The normal steel shows the combined effect of σ and chromium carbide precipitates; the Ti-treated steel shows that of σ only.

The greater embrittlement of the coarser-grained steels for a given σ content appears to be explained mainly by the semi-continuous grain-boundary film of precipitated σ, which is not seen in fine-grained steels. Sigma contents below 5% in coarse-grained steels (A.S.T.M. grain size 3) are distributed in the grain boundaries, but larger amounts also result in acicular formations within the grains. The results suggest that grain-boundary σ in coarse-grained steels is more harmful, accounting for practically all the Izod-impact embrittlement.

The influence of carbide precipitation is also more pronounced in coarse-grained steels, but its additional embrittling effect is limited. In the absence of σ, however, it can account for reductions of 15% elongation and 70 ft.lb. Izod-impact resistance.

The hot ductility of steels containing σ is somewhat better than the room-temperature ductility. Thus, tests on a coarse-grained steel (A.S.T.M. grain size 1–2), with 20% of σ precipitated at 800° C., gave the following results:

Temp. of Test, ° C.	U.T.S., tons/sq. in.	Elong., %	Red. in A., %	Izod, ft.lb.
15	29·5	3	1	1
800	19·9	14	16	9

This is in line with the results obtained by Guarnieri, Miller, and Vawter.[8]

The rate of σ precipitation depends on composition, temperature, and prior mechanical and heat-treatment.

The composition of the steel determines the degree of supersaturation of the austenite with respect to chromium, and from this, the rate of precipitation at any temperature below the prior annealing temperature at which the steel may be subsequently heated. Thus, a fine-grained steel with a potential σ content of 5% will take at least twice as long before equilibrium is approached at 800° C. as a similar fine-grained steel that is capable of forming 20% of σ.

The temperature at which the steel is heated influences both the degree of supersaturation and the rates of diffusion of the alloying elements. These are opposing effects, but over wide ranges of temperature the latter will be more important.

The prior heat-treatment of the steel may influence grain size. Coarse grain size has a remarkable effect in slowing down the rate of σ precipitation in steels with potential σ contents of 10% or less. This appears to be due to the difficulty of nucleating precipitates within the grains when the degree of supersaturation of the austenite grains is low. Coarse grain size, on the other hand, appears to have little influence on the rate of precipitation in steels that precipitate 20% or more of σ, because extensive precipitation then occurs throughout the grains, and the distances over which diffusion has to take place are relatively small.

Prior cold work accelerates the rate of precipitation, presumably because it facilitates nucleation, but the effect is small in fine-grained steels unless heavy deformations are applied, *e.g.*, 40% elongation. If cold work is applied to coarse-grained steels, however, it is very much more effective.

Metastable phases occurring in 25/20 steels include chromium carbide and ferrite. The metastable carbides are in the nature of an excess carbide precipitation occurring in the early stages of heating and subsequently dissolved in the austenite as it continues to lose chromium by the slow formation of σ. The stable austenite can dissolve more carbon because it has a lower chromium content. Under the microscope, carbide precipitates appear to be replaced by σ as the steel approaches its equilibrium condition.

Table XI

EFFECT OF SIGMA ON MECHANICAL PROPERTIES OF FINE- AND COARSE-GRAINED STEELS

Sigma at 800° C., vol.-%	Normal 25/20				Ti-treated 25/20			
	Elong., %		Izod, ft.lb.		Elong., %		Izod, ft.lb.	
	F	C	F	C	F	C	F	C
0	52	62	120	120	52	55	120	120
5	36	17	28	10	42	31	47	16
10	28	5	11	2	33	16	20	6
15	24	3	8	1	24	8	11	4
20	22	3	8	1	15	5	7	3

The σ-free condition is that immediately after the prior annealing treatment
F = Fine-grained (1050° C. annealed): A.S.T.M. grain size 5–8
C = Coarse-grained (1150° C. annealed): A.S.T.M. grain size 0–6

Metastable ferrite occurred as an intermediate phase during the redissolving of σ in austenite at temperatures of about 1050° C. In steels with free carbon, the metastable ferrite is very short-lived, because chromium carbides precipitate rapidly in the ferrite zones.

If the choice of steel for a particular application depends on considerations of σ embrittlement and oxidation resistance, it may not be necessary to use a completely σ-free steel. It has been shown that fine-grained steels (*e.g.*, 0·03 mm. grains) are capable of giving 30% elongation in a tensile test, even with 10% of σ present, although the impact value is low. This is consistent with the very satisfactory service record of wrought 25/20 steels. However, the same amount of σ in coarser-grained steels (*e.g.*, 0·15 mm. grains), such as result from annealing at 1150° C. instead of 1050° C., or from mass effects, can cause serious embrittlement. In such cases, only about 2% of σ can be tolerated if room-temperature ductility must be preserved. The data presented facilitate the choice of steels on this basis.

Acknowledgments

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Further Correspondence on the Paper—

COLD ROLLING WITH STRIP TENSION*

By H. Ford, F. Ellis, and D. R. Bland

Mr. **M. F. Dowding** (Davy and United Engineering Co., Ltd.), wrote: In his reply to my contribution to the discussion on the above paper, Professor Ford has, I think, exaggerated the difference in accuracy between the two methods.

In computing the powers and loads for a projected new mill it is necessary to work out a number of programmes each requiring a large number of passes. Using the nomographic method each pass can be computed and corrected for back and front tension in about 1½ min., whereas in his paper Professor Ford states that the average time of calculating one pass by his method is about 20 min. Therefore, to compute, say, 100 passes would take 2½ hr. by the nomographic method and about 4 days by Professor Ford's method. In fact, the 20 min. average mentioned in his paper can only be achieved if R' converges rapidly; but in computing a programme to roll tinplate on a 21-in. dia. work roll the phenomenon of minimum thickness is encountered and R' does not converge rapidly so a great deal of time could be spent in finding the limiting rolling conditions so that passes may be suitably modified.

The nomographic solution includes the effect of roll distortion; it gives a value of the minimum thickness in rolling, and is very quick to apply. Its normal accuracy is generally less than ± 10%, and the accuracy of the Hessenberg and Sims method is about the same, except in certain well-known cases. Readings now being obtained from loadmeters installed on large industrial mills are confirming these accuracy tolerances.

In my contribution to the discussion I did not want to detract in any way from the value of the work done by Professor Ford on this subject, and of course it is vitally important to have a method available to give an almost exact value for a pass which is in doubt by a less accurate method. However, I still emphasize that for day-to-day calculations on projected mills when they are taking shape a quick and flexible graphical solution is extremely useful to the designer who wants to ring the changes on possible programmes to find the most economical answer for his customer.

I do not think that Professor Ford intended it in this way, but his reply in effect accuses us, as mill builders, of being careless in our designs. That this is not so is borne out by the very large number of rolling mills we have in operation which are doing their duty to the great satisfaction of the people who bought them.

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* *J. Iron Steel Inst.*, 1951, vol. 168, May, pp. 57–72. For the Discussion, Correspondence, and Authors' Replies, *see J. Iron Steel Inst.*, 1952, vol. 172, Sept., pp. 28–40.

Effect of Direction of Rolling, Direction of Straining, and Ageing on the Mechanical Properties of a Mild-Steel Plate

By Constance F. Tipper, M.A., Sc.D.

SYNOPSIS

A series of experiments was carried out on mild-steel plate to determine the effect of plastic strain and ageing on notch-impact results and yield point, with the special purpose of investigating directional effects.

Direction of rolling was found to be most significant in Izod-impact tests, the lowering of these values after prestrain being chiefly due to work-hardening and strain ageing. These factors also raised the yield and ultimate tensile stresses, and caused loss of ductility.

Direction of straining was found to affect the yield chiefly, both in value and shape. No satisfactory explanation could be found to account for the absence of a recovered yield after ageing.

It is a common property of rolled plate that the energy absorbed in notch-impact tests may differ considerably, according to the direction in which the test pieces are cut from the plate, and according to the position of the notch in the test piece. These differences are attributed to the degree of lamination of the ferrite and pearlite in the plate, and to the character and distribution of the non-metallic inclusions. Preferred orientation of the crystals has not been found to occur to any extent in hot-rolled plate.[1]

If elongated inclusions are placed perpendicular to the direction of straining, a high stress concentration may be engendered at the ends. Moreover, in any situation, particularly if the stresses are non-uniform, there is a tendency for separation to occur on straining between the metal and non-metallic inclusions, owing to lack of cohesion between materials of different chemical composition and with different elastic constants.[1, 2] The rôle of inclusions in initiating fracture has been established; their part in initiating yield is not easy to determine, although it may be presumed to exist.

The following experiments were made to determine the effect of plastic strain and ageing on notch-impact test results, and on the yield point of a mild-steel plate, with the special purpose of investigating directional effects.

COMPOSITION AND MECHANICAL PROPERTIES OF PLATE

The analysis of the ½-in. mild-steel plate used in the experiments was as follows:

Carbon	0·12%	Molybdenum	<0·03%
Silicon	0·02%	Tungsten	<0·02%
Manganese	0·48%	Vanadium	<0·02%
Phosphorus	0·019%	Aluminium	0·005%
Sulphur	0·037%	Copper	0·12%
Nickel	0·14%	Nitrogen	0·007%
	Chromium	<0·03%	

Tensile tests on the full plate thickness, made on a 50-ton Buckton lever machine, gave the following results:

Width 1 *in., thickness* 0·510 *in.*

	L	*X*
Yield stress, tons/sq. in.	16·95	15·20
U.T.S., tons/sq. in.	24·80	24·60
Elongation on 3 in., %	44	40
Reduction in area, %	60	51

Width 3 *in., thickness* 0·510 *in.*

Yield stress, tons/sq. in.	16·35	16·85

The figures of yield approximate to the upper yield stress; those in Table II refer to lower yield stress.

The results of previous Izod-impact tests are shown as full lines in Fig. 1. This plate has marked directional properties, but showed no preferred orientation in back-reflection X-ray photographs.

EXPERIMENTAL PROCEDURE

Large test pieces of full plate thickness, 18 in. long by 3 in. wide, were cut from the plate in and transverse to the direction of rolling. They were marked in 2-in. lengths by fine scribed lines. They were then extended until yield had taken place throughout the parallel portion. The overall extension in the first two bars tested was found to be 3·75% after removal of load. Two further test pieces were prepared and extended about 10% to increase the plastic strain and obtain larger effects. The stresses are given in Table I. These values are high compared with those obtained on the small Hounsfield test pieces.

Uniformity of deformation was checked by taking measurements over the parallel portion. Differences over successive 2-in. gauge lengths were within 0·5%. After 10% extension, a little fibre was shown in an X-ray photograph.

The uniformly strained portion was then machined into test pieces as follows:

Single-notch Izod-impact test pieces of standard dimensions were cut in the direction of straining and

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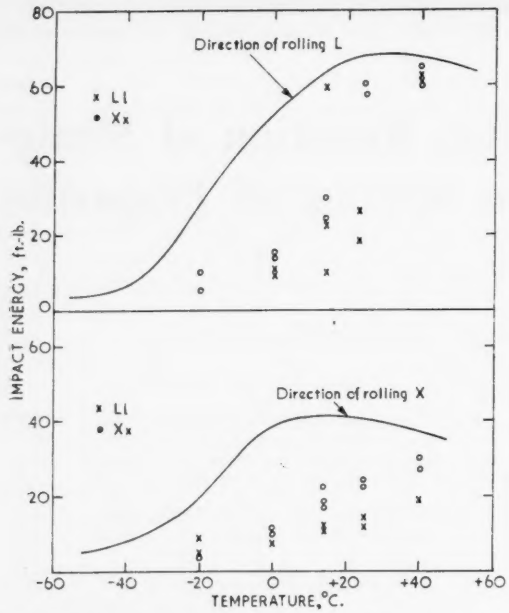

Fig. 1—Relation of 10% prestrain to direction of rolling. Smooth curves represent mean of results obtained from untreated plate.

transverse to it. The notch was machined perpendicular to the plane of the plate. Hounsfield tensile test pieces, 0·25 in. in diameter, were made so that on subsequent testing they would be extended in the same direction as the original bar was pulled, and transverse to this direction.

Compression tests were also made in the two directions of rolling and straining. Two sizes of test piece were used for this purpose. To avoid buckling of the specimen, the length/diameter ratio was kept at less than 1·5; since the maximum load attainable on the Hounsfield machine was 2 tons, the diameter of samples compressed in this machine was 0·270 in., and the height 0·375 in. Larger samples, of diameter 0·375 and height 0·500 in., were tested in a 10-ton Avery lever machine. In both cases, the specimens were compressed between guided plates, the surfaces well covered with Vaseline, and only the yield stress was determined, so that plastic deformation and barrelling of the specimen are insignificant.

Records were obtained as usual on the Hounsfield machine. In the Avery machine, measurements were made with a micrometer on projecting arms attached to the compression anvils at loads increasing by 0·1 ton. The onset of yielding was easily discernible by the falling beam as well as by measurement. The figures were somewhat higher than those obtained on the Hounsfield machine, where the deviation from the straight line was taken as the load at yield, or the lower value when any drop in the mercury column was detected. The Hounsfield figures are probably more accurate, and are directly comparable with the tensile tests on the same machine.

These test pieces were boiled for 15 min. Some samples were later given a further treatment of ½ hr. at 250° C. Finally, one tensile and one compression test piece of each group were heated for 1 hr. at 650° C.

The system of marking the specimens is as follows: L = large test piece cut in the length direction of rolling; X = large test piece cut transverse to the direction of rolling. If the small test piece has been cut so that its long axis is in the direction of straining of the large test piece, it is designated by l, and if cut perpendicular to this direction, by x. Hence, Ll indicates that the material was strained in the direction of rolling, and that the test sample was cut in the direction of straining.

The results of impact, tension, and compression tests are given in Tables I and II, and plotted in Figs. 1 and 2.

There are two variables to consider: the directional properties of the material produced by the original rolling, and those introduced by the straining.

The marked effect of direction of rolling persists

Table I

IZOD TEST RESULTS

Ref. No.	Temp., °C.	Ft.lb.	Fracture Appearance; % Crystalline*
1st Large Test Pieces, Ext. 3·75%, boiled			
Ll	−40	3	C
	−30	5	C
	−20	4	C
	−10	9	90
	0	18	90
	+ 4	24	80
	+ 6	34	75
	+ 8	77	F
	+14	72	F
Lx	−20	8·5	90
	−10	15	90
	0	19	75
	+ 9	22	60
	+18	27·34	40 F, patch C
Xl	−40	2	C
	−20	6	C
	− 2	15	80
	+ 5	20	75
	+20	33	F, specks C
	+35	38	F
	+40	34	F
	+50	33	F
Xx	−30	4	C
	−10	20	90
	0	17	90
	+12	75	F
	+30	74	F
2nd Large Test Pieces, Ext. L = 10·5%, X = 9·5%, boiled			
Ll	0	10, 11	80, 90
	+14	10, 60, 23	90, F, 75
	+25	19·27	80
	+40	61, 63	F
Lx	−20	9·5	C
	0	8, 9	C
	+14	11, 12	90
	+25	12, 14	80
	+40	19	75
Xl	−20	3	C
	0	9, 11	80
	+14	17, 18, 22	75, 60
	+25	22, 24	...
	+40	30	F, specks C
Xx	−20	5, 10	C
	0	14, 15	90
	+14	30, 25	75, 60
	+25	58, 61	F
	+40	65	F

*F = Fibrous, C = Crystalline

through all the impact tests, and far exceeds any change introduced by altering the direction of straining. This is clearly seen in Fig. 1, where the results of a prestrain of about 10% are compared in relation to directions of rolling. The smooth curves were obtained by drawing a mean curve through a large number of results obtained for both directions of rolling. There are insufficient points to justify drawing curves through those values obtained from the strained material.

The tensile tests, on the other hand, show little effect from the rolling, except in the reduction-in-area figures, which are consistently high in the length direction of rolling compared with the transverse, irrespective of variation in the other values. Two figures are generally given, owing to anisotropy of material. Yield and ultimate stresses and elongation are all affected by direction of straining and treatment.

Owing to the very short gauge length and large end-effects, the degree of accuracy in determining the yield in the compression tests is not as high as in the tensile tests, but the results are in the direction that might be expected. The effects of work-hardening and ageing are greater than those due to straining.

RESULTS

Izod Test Results

The first effect of the prestrain is to lower all the values of energy absorption, particularly in the transition range. At the same time, partly crystalline fractures are obtained at higher temperatures. This is most clearly seen on comparing fracture appearance from tests made on test pieces prestrained 3·75% with those strained 9·5 or 10·5% (*see* Table I). In the untreated plate, the fractures are fibrous at about 20° C. in both directions of rolling.

It may be inferred from these observations that the lower energy absorption is due to reduction in ductility, which is not compensated by the increase in strength caused by work-hardening. This conclusion is supported by the tensile tests, reported in Table II.

The decrease in ductility may act in two ways. Assuming that some plastic deformation precedes fracture, a previously strained steel has already begun to fracture. Furthermore, for the same initial geometry of notch, the fracture stress is reached while the stress concentration is high, and a higher stress gradient would be maintained during the propagation of fracture, so that the true stress at the advancing crack front remains high.

The higher temperature at which crystalline fractures appear is more difficult to explain. If, as a result of prestraining and ageing, precipitation and segregation of a constituent occur on the glide or cleavage planes, the result might tend to raise the temperature at which cleavage in certain suitably orientated crystals took place, just as a change in composition might.

It is also possible that an apparent increase in crystallinity results from fracture on an increased number of shear planes as well as on the crystallographically different cleavage planes. In a fine-grained steel, the distinction is difficult to make after plastic deformation has taken place.

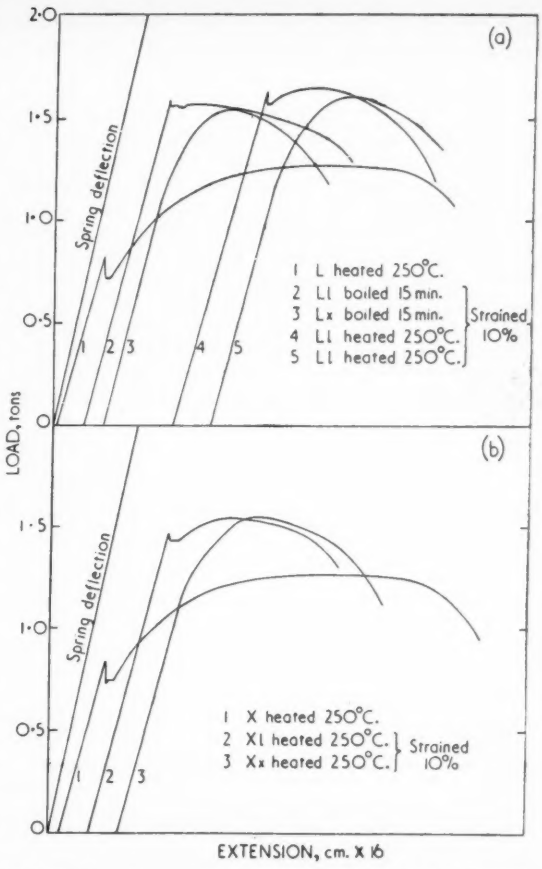

Fig. 2.—Load extension curves obtained in the Hounsfield tensometer for specimens cut: (*a*) in the length direction of rolling; (*b*) transverse to the direction of rolling.

In regard to the direction of straining, the differences are slight, but there is a general tendency for the energy figures to be slightly higher when the fracture path is in a direction transverse to the direction of straining, *i.e.*, in the *Ll* and *Xl* test pieces. This holds for both rolling directions.

Tensile Test Results

Table II gives the collected results for both directions of rolling and straining and for the treatment after straining. Figures 2*a* and *b* reproduce curves plotted on the Hounsfield tensometer, and show the great difference in the character of the yield when the test pieces are subsequently tested in the direction of straining and transverse to this direction. These differences persist after heating at 250° C., where full ageing and recovery might be expected to have taken place. In making calculations of the yield stresses, the lower yield load was adopted for all curves that showed an upper and lower yield, and the point at which the curve deviated from the straight line in those instances when a marked yield was absent.

Both yield and ultimate stresses are raised by

strain-ageing, with a corresponding decrease in ductility for all test pieces. To compare them in greater detail, it should be remembered that the directions *Ll* and *Xx* both refer to the length direction of rolling, and *Lx* and *Xl* to a direction transverse to it. This is clearly shown by comparing figures for reduction in area, which of all the values appear to be most closely related to direction of rolling, and, as already pointed out, are unaltered by direction of straining. It should also be remembered, however, that all the test pieces cut from the *L* and *X* test pieces, although similarly cut from the same plate, may differ from each other as a group. The overall extensions in the large test pieces differed by 1%. Allowing for such differences, it is difficult to decide if direction of straining has produced a greater effect when applied to the length than to the cross direction of rolling, since the figures are very close.

Treatment at 650° C. has removed all effects of strain. The high yield stress may be attributed to refinement of the ferrite.

Compression Test Results

On the grounds that extension in one direction produces a contraction in a direction at right-angles to it, the effect of prestrain on the yield in the direction designated by *l* in the tensile tests corresponds to the direction *x* in compression, and *vice versa*. Both directions give values that are below those obtained in tension, owing probably to the inaccuracies already mentioned, but the values of direction *x* are now above those of direction *l*, as predicted.

To check on the reliability of the compression tests

Table II

TENSION TESTS AND COMPRESSION

Treatment	Direction *L*				Direction *X*			
	Yield Stress (Tons/sq. in.)	Max. Stress (Tons/sq. in.)	Elong., % on 0·98 in.	Red. in Area, %	Yield Stress (Tons/sq. in.)	Max. Stress (Tons/sq. in.)	Elong., % on 0·98 in.	Red. in Area, %
As-rolled; mean of 4(*L*) and 2(*X*)	14·3	25·19	41	66–70	14·3	25·17	36	56–59
Heated at 250° C. for ½ hr.	14·3	25·5	35	62–68	14·9	25·6	34	55–60
	Direction *Ll*				Direction *Lx*			
Strained 3·75%, 18·65 tons/sq. in., boiled	21·9	27·1	30	62–66	16·4	26·7	27	53–55
Strained 10·5%, 25·55 tons/sq. in., boiled	31·0 30·5	31·3 31·3	20·5 21·5	60–62 60	21·3 21·0	30·75 31·0	20 18	50–52 48–52
Strained 10·5%, boiled, heated at 250° C. for ½ hr.	31·15	32·7	21	57–60	25·0	32·0	18	48–52
Compression: Avery 10-ton	20·15	...	...	...	22·60 22·85	...	...	...
Hounsfield	18·55	...	...	...	22·25	...	...	...
Strained 10·5%, boiled, heated at 650° C. for 1 hr.	20·05	28·3	34	65–70	20·05	27·6	34	56–60
Compression: Avery 10-ton	19·25	...	...	...	...	...	...	...
Hounsfield	17·75	...	...	...	...	...	...	...
	Direction *Xl*				Direction *Xx*			
Strained 3·75%, 18·2 tons/sq. in., boiled	21·5	26·6	26	57–60	15·6	26·5	29	65–68
Strained 9·5%, 23·1 tons/sq. in., boiled	28·3 28·3	29·6 29·5	19 19	45–48 48–50	21·1 20·8	29·5 29·3	22 22·5	62 60–62
Strained 9·5%, boiled, heated at 250° C. for ½ hr.	28·7	30·7	21	40–45	25·0	31·0	22	56–60
Compression: Avery 10-ton	20·2 20·1	...	...	...	22·85	...	...	...
Hounsfield	18·8	...	...	...	21·25	...	...	...
Strained 9·5%, boiled, heated at 650° C. for 1 hr.	19·15	26·35	32	53–56	20·0	26·6	34	65–70
Compression: Avery 10-ton	...	...	...	...	20·15	...	...	...
Hounsfield	...	...	...	...	17·85	...	...	...

L = Large test piece cut in direction of rolling
Ll = Cut from *L* in direction of straining
Lx = Cut from *L* transverse to direction of straining
X = Large test piece cut transverse to direction of rolling
Xl = Cut from *X* in direction of straining
Xx = Cut from *X* transverse to direction of straining

compared with the tensile, specimens were heated at 650° C. for 1 hr., and the figures given in Table II show the same trend compared with the tensile tests for the same treatment.

Thus, the compression tests may be said to confirm the results of the tension tests, in indicating that work-hardening and strain-ageing have taken place, and also that direction of straining affects the yield stress in the way expected.

DISCUSSION OF RESULTS

Two well-established effects of plastic strain are involved in these experiments. One is the recovery of iron and mild steel after overstrain, and the other is the Bauschinger effect.

The early experiments of Muir[3] established that if iron or mild steel were strained beyond the yield point, unloaded, and immediately reloaded, they no longer obeyed Hooke's law up to the yield, nor was there a definite yield as on the first loading. Muir was chiefly concerned with elastic recovery, and his loading and unloading curves showed a large loop that gradually closed, until the material again obeyed Hooke's law after a certain time interval had elapsed between the initial release of load and reloading. A higher yield stress was obtained with complete recovery of the characteristic yield. Low-temperature heating accelerates the recovery. Muir also showed the same effect in compression.

If a compression specimen were cut from one already strained in tension, the material showed a depressed yield and did not obey Hooke's law, but again recovery took place until the yield in compression was equal to the raised yield in tension. The raised yield in tension (or compression) was always accompanied by loss of ductility when the specimen was broken.

Recent investigations[4, 5, 6, 7] have shown that the phenomenon of the yield point and recovery from overstrain are both related to the presence of carbon and nitrogen in polycrystalline material and in single crystals. An explanation of recovery of the yield point put forward by Cottrell and Bilby[8] depends upon the presence of carbon or nitrogen as a means of locking dislocations.

The Bauschinger effect[9] is concerned with the change in elastic properties on reversing the direction of straining. If a material is plastically strained in tension and then compressed, the elastic limit is less in compression by the amount that the tensile strain raised it in tension, and *vice versa*. Recovery occurs on heating. The Bauschinger effect has been shown in metals such as copper,[10] in which no changes occur, similar to that of strain-ageing in mild steel, and in single crystals.[11]

A recent paper,[12] which summarizes the previous investigations on the Bauschinger effect, describes torsion tests on a number of metals, including single crystals, in which it was found to a greater or lesser extent. It is concluded that the effect is not wholly explained on the hypothesis of internal stresses alone.

Further work that may have some bearing on the present problem is that of Swift[13] on steel, and the extension of Swift's experiments at the Massachusetts Institute of Technology to copper, brass, Monel, and aluminium. Prestraining in one direction followed by testing to destruction by a different method, such as twisting followed by pulling in tension, alters the mechanical properties in an entirely inexplicable way on the basis of the plastic deformation undergone. One of the most striking changes is in the fracture, the character of which is restored on reversing the twist. An explanation has been put forward on the supposition that microcracks already existing in a harmless arrangement are moved to certain preferred orientations by the first straining, and moved back by subsequent treatment.[14] This explanation closely resembles that put forward in connection with previous results, which led to the initiation of the present investigation. It must be emphasized, however, that the treatment accorded in the present tests does not affect reduction in area and mode of fracture.

In the present investigation, the degree to which the direction of straining alters the yield stresses can be estimated by comparing the figures in tension and compression for the same direction; it will be noticed that there is a large discrepancy, of about 3 : 1, which is larger than would be expected if it were due to a Bauschinger effect, or can be attributed to experimental errors. Moreover, there is the marked difference in character of the yield, which would appear to be independent of the values of the yield stresses, and this difference is only removed on heating at 650° C., *i.e.*, at a temperature at which the ferrite recrystallizes. It is regrettable that the short compression specimens, with their excessive end-effects, make it impossible to investigate the yield-point strain. After heating at 650° C. there was a marked drop in load at the yield, and a very slight similar movement was noticed in some of the other specimens, but no true comparison is possible.

Summarizing the evidence, it appears that plastic straining in tension causes work-hardening and ageing, both of which cause an increase in yield and ultimate stresses and loss of ductility. Loss of ductility is indicated by drop in elongation figures and also by a fall in impact values and, since reduction in area is less affected, it implies drop in uniform extension. These general effects are common to both directions of testing after straining.

In addition, there is the directional effect on the value of the yield stress, which cannot wholly be attributed to a Bauschinger effect, and the difference in character of the yield corresponding to the direction of testing after straining. The mechanism that has been suggested to explain recovery of a yield by the migration of carbon and nitrogen does not admit a directional effect of this nature. Yet the connection between the characteristic yield in mild steel, ageing, and the presence of carbon and nitrogen has been established on the basis of so much experimental evidence as to be undisputed.

Another explanation is possible on the basis of the formation of micro-cracks on the first straining. If such cracks or discontinuities are formed, enlarged, or altered in shape, a permanent effect is produced that is not obliterated by reversal in the direction of straining. It is difficult, however, to reconcile the increased ultimate stresses with the presence of micro-cracks.

SUMMARY AND CONCLUSIONS

A study of the direction of rolling and straining on the notch-impact test results and tension and compression tests of a mild-steel plate indicates the complexity of the contributing factors.

Direction of rolling is most significant in Izod impact tests. The lowering of values in impact following prestrain would appear to be chiefly due to work-hardening and strain-ageing, which affect both directions of rolling equally.

The raising of the yield and ultimate stresses and loss of ductility in tensile tests are also due to the same causes.

Direction of straining chiefly affects the yield, both in value and shape. While the Bauschinger effect may account partly for some of the observations, it cannot explain the absence of a recovered yield after ageing. Nor is the theory of Cottrell and Bilby about the part taken by carbon and nitrogen on recovery compatible with the experimental evidence. The micro-crack theory explains the directional effect of straining on the yield, but it is inconsistent with an increased U.T.S., unless it can be assumed that in a ductile material subsequent plastic deformation obliterates the discontinuities. Preferred orientation may be excluded as an explanation on the ground that it is slight.

To separate the factors that may be influencing the results obtained in these experiments, it would be desirable to repeat them with a non-strain-ageing steel, and with a metal which is isotropic, both mechanically and structurally.

Since completing this work, the author has seen the papers of Ripling[15] and Ripling and Baldwin,[16] where the effects of prestrain on notch brittleness have been investigated. Their results do not support the theory of the presence and alignment of micro-cracks.

Acknowledgments

Thanks are due to Dr. E. O. Hall for making the necessary X-ray photographs of the material used in these experiments. This investigation has formed part of one being carried out on behalf of the Admiralty into the brittleness of structural mild steel under the direction of Professor J. F. Baker, O.B.E., Sc.D. at the Engineering Department, Cambridge University.

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RESEARCH ON THE CONSTITUTION OF ALLOYS

Several significant gaps in current research on alloy constitutions are commented on in a statement by B.I.S.R.A.'s Constitution of Alloys Group (Chairman: Professor G. V. Raynor). Suggested lines of research are:

(i) Further study of high-temperature materials, particularly the higher-melting-point alloys of Groups V and VI. More information is required on systems containing borides, and on equilibrium relations in ferrous alloys containing silicides.

(ii) Systematic work in the binary alloys of iron, as a basis for studies of complex equilibria involved in binary and quaternary alloys.

(iii) A more concentrated study of the constitution of magnesium alloys, particularly ternary and more complex alloys.

(iv) Investigation of the constitutional background required for the proper development of materials of the high-tensile brass type and complex bronzes.

(v) Further study of the crystal structures of intermetallic phases, and of the purely physical problems (*e.g.*, X-ray emission and absorption, magnetic properties, low-temperature specific heats) connected with the theory of metals and alloys.

The Group is prepared to suggest systems requiring investigation, and to put enquirers in touch with other workers in the same or similar fields. It would be glad to know of existing equilibrium diagram work which has not been reported to it, and of projected research programmes involving the constitution of alloys. In particular cases, where the results of such work are likely to be of direct interest to the iron and steel industry, the Group is able to make recommendations for some financial assistance.

Those interested should communicate with the Secretary, Constitution of Alloys Group, B.I.S.R.A., 11 Park Lane, London, W.1.

The Stress-Corrosion Cracking of Mild Steels in Nitrate Solution

By R. N. Parkins, B.Sc., Ph.D., L.I.M.

SYNOPSIS

An attempt has been made to discover the reason for the formation of intergranular macro-cracks in mild steels subject to static stress and the corrosive environment of a boiling calcium–ammonium nitrate solution. The most significant fact emerging from the work is a relationship between the carbide distribution in the material and its propensity to this type of failure. This result is indicated by a study of mild steels of differing carbon contents, and also by heat-treatments at subcritical temperatures *in vacuo* and in moist hydrogen.

The experimental evidence suggests that the applied stress plays a larger part than merely pulling open the crack already formed to allow more corrosive liquid to reach the base; it is also shown that cold plastic deformation has a marked effect in increasing the susceptibility to stress-corrosion cracking. A further relationship is indicated between the lattice distortion of the grains, as measured by the X-ray method, and the tendency to stress-corrode.

The results are interpreted as indicating that susceptible mild steels have an almost continuous film of distorted ferrite in the region of the grain boundaries, and a theory that this distortion is sufficient to make the boundary regions anodic to the rest of the grain is suggested.

Introduction

THE application of a static stress to a metal undergoing corrosion will, in some cases, cause increased corrosion and consequent increased deterioration of mechanical properties. More specifically, the conjoint action of prolonged stress and corrosion sometimes causes cracks of the type associated with brittleness, which follow some of the grain boundaries and rapidly penetrate through the section of the metal. The present work is concerned with the latter circumstance, *i.e.*, where static stress and specific corrosive environment combine to cause intergranular macro-cracks.

The earliest instances of intergranular corrosion in mild steel to receive attention were concerned with boiler failures,[1–4] which closely resemble those failures observed in vessels containing nitrate solutions,[5, 6] in that the cracks are intergranular, and need mildly corrosive conditions as well as a state of high static tensile stress for their occurrence. During the last few years, stress-corrosion cracking in mild steel has become more alarming owing to a large number of failures in welded structures conveying crude coal and coke-oven gas.[7, 8] It has been suggested[6, 9] that these examples of stress-corrosion are metallurgically similar.

Although many of the initial studies were designed largely to find an immediate practical solution to the problem, rather than to determine its fundamental cause, many suggestions as to the latter have been made. Jones[6] was one of the first to make a systematic study of the phenomenon, and his results led to an appreciation of the importance of stresses above a certain value being present before failure occurred, and also of the influence of different corrosive solutions. The mechanism of failure that he suggested was similar to that previously proposed by Andrews[2] and Merica,[4] whereby the corrosion weakened the grain boundaries owing to the absorption of hydrogen by the intercrystalline amorphous material. This has probably been the most widely accepted of the purely chemical theories, although Schroeder and Berk,[11] in their work on boiler failures, were unable to produce intercrystalline cracks by generating hydrogen at the surface of stressed specimens, which has been confirmed in the present work. Similarly, highly susceptible steels are not rendered more immune by prolonged vacuum-annealing to remove any hydrogen that may be present before corrosion.

Other early workers[10, 12] put forward theories in which the stress factor received greater emphasis than in the hydrogen embrittlement theory.[6] Thus, Fletcher[12] suggested that the high stresses at the bottom of cracks inherent in the surface of the steel would render the metal there more anodic than the rest, so that corrosion would be concentrated at such points. Mears,[13] however, states that thermodynamic calculations indicate the voltage difference to be too small for corrosion to take place in this way. The assumptions made in the calculation are not shown in the paper, but the result would appear to contradict recent experimental results obtained by Simnad and Evans,[14] and confirmed for the conditions of the present work by similar experiments.

Other early publications ignored the corrosion aspect entirely in stating that the mechanical stresses, *i.e.*, the sum of any locked-up stresses due to welding or riveting and applied stresses, were alone adequate to cause failure; McAdam[15] later proposed a mechanism based on his experience with corrosion fatigue. He considered that corrosion produced small pits, and cracking proceeded by essentially mechanical means through stress concentration at the base of the pits.

It is now recognized that any theory must account for both the stress and corrosion aspects of the problem, since the removal of either will render susceptible mild steels immune from cracking. This approach has led to the 'precipitation theories,'[7, 6] characterized by the 'Generalized Theory of Stress-

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Corrosion of Alloys' of Mears, Brown, and Dix.[17] Their conclusions are derived largely from their own work on aluminium alloys containing copper, but the theory is very similar to those that have been proposed for steel. Basically, the theory considers that precipitation of a phase within the grain boundaries renders such regions anodic to the grain interior, either because the precipitate itself is anodic, or because the region adjacent to the precipitate is impoverished of solute atoms and, hence, less noble than the solid solution forming the body of the grain. The function of the stress is assumed to be to pull apart the crevices so formed and allow more corrosive solution to attack the material at the base, thus extending the crack.

In the application of this type of explanation to mild steel, iron nitride[18] has been suggested as the phase precipitating within the grain boundaries and, in this case, suffering direct attack. The theory postulates that a minute crack forms at the boundary, for instance, by chemical attack, and stress concentration at the bottom of this crack accelerates the precipitation of iron nitride at the grain boundaries. The iron nitride is assumed to form from the nitrogen remaining in the steel after all the aluminium, added as a deoxidant, is converted to more stable compounds, including the nitride; from this, a 'free-nitrogen factor' has been evolved, which is claimed to give a measure of the stress-corrosion cracking propensities of mild steels. This factor, from which the amount of free nitrogen in the steel can be calculated, is

$$(2N\% + P\% - Al\% - 0{\cdot}1C\%) \times 10^5$$

corrected to atomic percent. It would appear from this formula that a simple relationship exists between the capacities for strain-ageing, assumed to be related to the nitrogen content, and the stress-corrosion tendencies of mild steels, and that deoxidation with aluminium should be highly effective in promoting resistance to intercrystalline attack.

The initial experiments[8] made in the present work were largely concerned with tests on welded plates, the object being to simulate the conditions of stress existing in welded gas mains, and thereby to study methods of preventing cracking. A broad correlation was found between the cracking propensities of steels subjected to the corrosive environment of crude coke-oven gas liquors and their susceptibility to a solution of calcium-ammonium nitrate. This solution was, therefore, adopted for studying the effect of varying the composition of the steel, and also the effect of treatments designed to alter the stress system left by the welding process. It was shown that annealing of the welded plates in the region 350–650° C. was highly effective in reducing failure, as also was peening, either by mechanical hammering or the use of cast-iron shot. It was also found that mild steels of widely differing character show a varying proneness to failure, which did not appear to be accounted for by the nitride theory of Waber and McDonald. The killing of the steel with enough aluminium to fix all the nitrogen as aluminium nitride, according to the Waber-McDonald formula, did not produce immunity, as their theory would predict. The experiments did, however, show that high-carbon steels were more resistant than low-carbon steels. For these reasons, and because of the restrictions imposed by the use of welded test plates, it was decided to study the problem more fully in an attempt to obtain a more complete understanding of the mechanism of failure.

EXPERIMENTAL METHOD

The present work has been based on normal commercial steels, whose analyses are shown in Table I, although various treatments performed on these before some of the corrosion tests have radically altered their composition and structure from the as-received condition.

These steels were chosen so that the suggestions of previous workers concerning the importance in stress-corrosion cracking of the carbon, nitrogen, and aluminium contents of the metal, and its mode of manufacture, could be tested.

Preparation of Test Pieces and Method of Stressing

For the quantitative study of stress corrosion, strip specimens, to which a known stress can be applied, are preferable to welded specimens, where the residual stresses are likely to vary greatly in direction and magnitude over small areas, and between specimens. Many devices have been used for stressing strip specimens,[19] ranging from small compact jigs, in which the specimen is usually bent as a beam by the restraint of the jig itself, to complicated machines, in

Table I
COMPOSITION OF MATERIALS USED*

Steel No.	C, %	Si, %	Mn, %	P, %	S, %	Al, %	N, %
0·07/*B*/*R*	0·07	0·02	0·38	0·047	0·033	...	0·011
0·08/*BOH*/*Ba*	0·08	trace	0·36	0·03	0·038	0·041	0·004
0·09/*B*/*M*	0·09	...	0·31	0·025	0·045	0·021	0·007
0·09/*BOH*/*K*	0·09	...	0·42	0·012	0·038	trace	0·005
0·11/*B*/*K*	0·11	0·04	0·64	0·049	0·035	0·067	0·013
0·16/*AOH*/*K*	0·16	...	0·47	0·033	0·047	0·011	0·003
0·18/*BOH*	0·18	...	0·52	0·016	0·047	trace	0·006
0·18/*BOH*/*K*	0·18	...	0·52	0·016	0·047	0·089	0·0035
0·22/*BOH*	0·22	...	0·55	0·019	0·051	trace	0·0045
0·22/*BOH*/*K*	0·22	...	0·55	0·019	0·051	(Ti) 0·15	0·004

* Method of Manufacture: *BOH* = basic open-hearth; *AOH* = acid open-hearth; *B* = basic Bessemer.
Ingot type: *R* = rimming; *K* = killed; *Ba* = balanced; *M* = modified.
All materials used were initially in the form of $\frac{1}{8}$-in. hot-rolled plate.

which the specimen is stressed in simple tension. Small jigs were used in the present work, because of their greater amenability to large-scale testing.

For a specimen stressed by bending as a beam, the method of loading may be by either three or four points of support. The advantage of the four-point method is that results are more reproducible, since, provided that the points are symmetrically spaced, four-point loading gives a constant skin stress over the area between the central points of support. With the three-point method, only a very small element of width directly above the centre support is at maximum stress. Thus, if, as would appear to be the case, all grain boundaries are not equally susceptible to penetration, the chances of cracking occurring in the four-point loaded specimen are much greater than in the three-point specimen. It was therefore decided to use four-point loading, on specimens about 6 in. long and 1 in. wide, with the points of support 2 in. apart.

In designing the jig to hold the specimens, it was borne in mind that the stress applied to the specimen had to be balanced by the jig itself so that, if the stress must not be relieved, the elastic deformation of the jig must be small compared with that of the corrosion specimen. Furthermore, by making the frames in mild steel, the magnitude of any possible galvanic action between corrosion specimen and holder was minimized.

The final form of holder and specimen is shown in Fig. 1. The specimen is supported and loaded by means of $\frac{1}{8}$-in. steel rods, 2 in. apart. Loading is carried out in a universal testing machine arranged for use in compression, the load being transmitted from the upper cross-head of the machine to the protruding ends of the cross-piece by **V** blocks. The beam of the machine having been balanced, the bolt is tightened until the beam is just on the point of becoming unbalanced, when the **V** blocks are removed, and the load on the specimen is transmitted to the jig.

All the specimens for corrosion tests were cut in the same direction from the plate material, to allow for any possible anisotropy resulting from rolling. They were sawn to a small oversize, so that the final dimensions could be achieved by milling. The mill scale

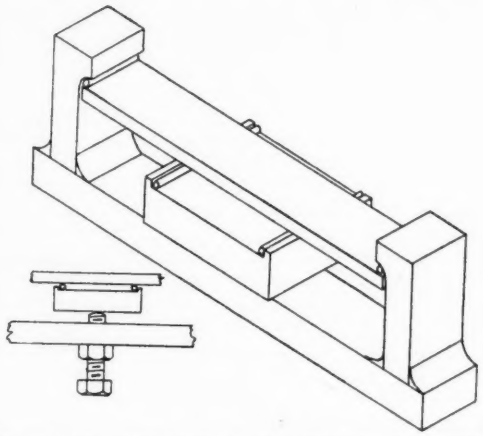

Fig. 1—Four-point method of loading stress-corrosion test specimens

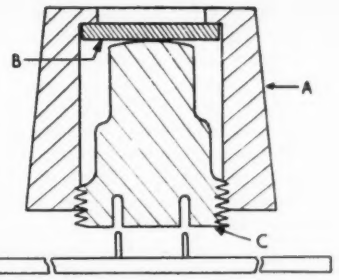

Fig. 2—Jig used for stressing disc specimens

remaining on the specimens after cutting was removed on a belt linishing machine, which produced a surface finish comparable with that obtained with a rough-grade emery paper.

To study cracking more closely than was possible in the tests performed in these jigs, a second type of stressing frame was made, in which a smaller specimen, observable under a microscope without removal from the jig itself, was used. These specimens were circular discs, $1\frac{1}{2}$ in. dia., $\frac{3}{32}$ in. thick, and were ground, polished, and lightly etched, as for normal microscopic examination, before being subjected to the corrosion test. The specimens were retained in a state of stress by loading in the jig shown in Fig. 2. The hollow mild-steel cylinder A is machined to the diametrical cross-section shown, and the specimen B is placed into it, with its polished surface uppermost. Stress is applied to the specimen by rotating the threaded rod C so that it pushes the centre of the disc beyond its equilibrium position, the periphery being retained by the projection shown.

With this arrangement, no attempt was made to impose calculated stresses on the specimen, different states of stress being distinguished merely as above or below the yield point. Indication of the yield point was given by the appearance of slip bands in the centre of the surface of the specimen; stresses below the yield point were applied by rotating C through a smaller angle than that required for the first appearance of slip bands.

Corrosion Test Solution

The solution containing calcium nitrate (860 g./l.) and ammonium nitrate (30 g./l.), as suggested by earlier researches, was held in a rectangular welded mild-steel tank, $\frac{5}{16}$ in. thick, 25 in. × 12 in. × 13 in. deep, and kept water-cooled to produce condensation.

Heat-Treatment in Wet Hydrogen and *in Vacuo*

Statements by previous workers indicating that steels heat-treated in wet hydrogen lost their susceptibility to intercrystalline corrosion cracking prompted some experiments in this direction. The decarburizing action of moist hydrogen passed over heated mild steel has been fully studied by Low and Gensamer,[20] who have stated the optimum conditions required for maximum effect. The carbon and nitrogen contents of the steel reach minimum value in the shortest time when the temperature of treatment is between 720° and 740° C., the hydrogen contains 30 vol.-% of water vapour, and a rate of gas flow of about 0·01 cu. ft./sec. is maintained. The hydrogen/

water-vapour mixture can best be obtained by passing dry hydrogen through water held at 60° C.

The apparatus used to achieve these conditions was an electrically heated mild-steel tank containing water, thermostatically controlled at 60° C., through which hydrogen was passed. The mixture of hydrogen and water vapour passed along heated tubes, to avoid condensation, to the silica tube furnace containing the specimens, which were kept at 730° C. during the period of the treatment.

Since the time taken for complete removal of the carbon from any steel depends on the thickness of the material, the time becoming very long for material thicker than $\frac{1}{8}$ in., the normal $\frac{5}{16}$-in. plate was hot-rolled to $\frac{1}{8}$ in., and was then subjected to wet hydrogen and certain other treatments.

Some experiments required specimens that had been given a prolonged anneal at about 700° C. to spheroidize the pearlite. Initially, this heat-treatment was carried out with the strips packed in cast-iron turnings enclosed in a heat-resisting box, to which a lid had been luted in order to reduce oxidation. Although the oxide film produced during such treatment was quite thin and was removed before corrosion testing, it was considered advisable to repeat the experiments on specimens that had been annealed *in vacuo*. This treatment left the surface unaltered, but the results obtained in the corrosion tests were identical with those obtained on specimens annealed in cast-iron turnings.

Nitriding and Carburizing of Wet-Hydrogen-Treated and Other Steels

It was found desirable during the present work to synthesize certain steels by introducing carbon and nitrogen in controlled amounts to give certain compositions.

The nitriding was effected by passing cylinder ammonia into a heated tube furnace, in which the specimens were kept at 850° C. Although these experiments were conducted on steel that had been rolled to $\frac{1}{8}$ in. thick, the nitrogen distribution was probably not uniform, and so a homogenizing treatment was added. The strips were water-quenched after nitriding and transferred to a second tube furnace, where they were heated at 900° C. for 18 hr. in a stream of purified nitrogen and cooled *in situ*. Microscopic examination indicated that this series of treatments produced an even distribution of the nitrogen, in the form of nitride needles, when the nitrogen content was low ; with higher contents, some surface concentration remained.

Carburizing was effected by heat-treatment at 950° C. in a carefully controlled hydrogen–dipentene gas mixture. After a few days, the mixture reached equilibrium with the carbon in the steel, in that no further increase in carbon content occurred, and the carbon had become evenly distributed through the specimen.

Cathodic Control of Cracking

A number of experiments have been carried out to determine the effect of applying cathodic potentials to specimens undergoing corrosion. No attempt was made to measure true current densities in these tests, but the reported values of the applied current will indicate the current density, since the combined area of corrosion test piece and loading jig was constant throughout the experiments. The proportionality is probably not direct, however, because of the variation of throwing power with the applied current.

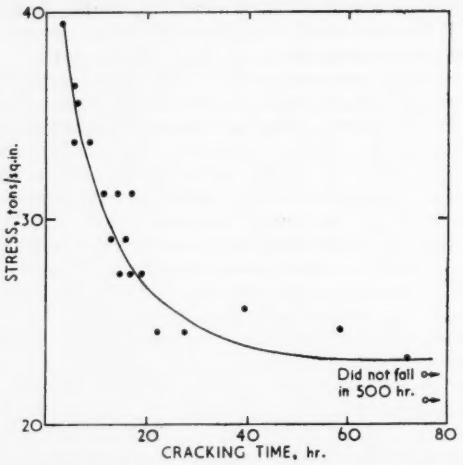

Fig. 3—Influence of applied stress on cracking time (taken as the interval to the appearance of the first crack)

A non-conducting frame was constructed in which two loaded jigs could be placed so that the corrosion specimens were insulated and opposite one another with their active surfaces 1 in. apart. One specimen was made the anode and the other the cathode in a cell in which the corrosive liquid was the electrolyte ; the remainder of the circuit included a metal rectifier, giving a steady current, a variable resistant, and an ammeter, all in series.

X-Ray Work

The experiments of Wood[21] and others[22] have shown that the lattice parameter of ferrite does not remain constant when mild steel is cold-worked, and that these variations can be accounted for by assuming the presence of micro-stresses left after plastic deformation.

In a preliminary series of experiments, towards the end of the present work, a simple type of back-reflection X-ray camera was used, in which the surface of the specimen to be examined was held perpendicular to the X-ray beam, and a flat film, in the same plane as the specimen, was rotated about the beam. The results were sufficiently encouraging to warrant more careful work, and for this purpose a new back-reflection camera was constructed.

The main disadvantage of the simple back-reflection camera was the difficulty of measuring the diameter of the reflected ring, owing to the broadening of the latter, and the large amount of background scatter on the film. These undesirable effects were partly surmounted by using a camera with a focusing principle in conjunction with a bent crystal monochromator giving only cobalt $K\alpha_1$ radiation. The specimen, in the form of a flat strip, was rotated in its own plane during the exposure and the result was corrected for film shrinkage.

EXPERIMENTAL RESULTS

Influence of Stress on Cracking Time

Tests were carried out in the nitrate solution on specimens stressed at different values. A typical series of results (*see* Fig. 3) shows that, as the stress is reduced, the cracking time (*i.e.*, the time taken for the appearance of the first cracks) becomes progressively longer until a minimum stress is reached, below which failure does not occur over a very extended period. The curve shown is for steel 0·11/*B*/*K*, but all the steels that have cracked during testing have given curves of this general form, although differing in the minimum stress required for failure.

Influence of Cold Work on Cracking Time

In testing the relative susceptibilities of various mild steels, it was found that in nearly every case it was not possible to cause cracking with the material in the as-rolled state. The results of some of the earlier workers and of the tests on welded plates in the present work[8] having shown that steels are rendered more prone to cracking by cold-working before testing, experiments were carried out in which steels resistant to intergranular attack in the as-rolled state were corroded after cold deformation of the strips in tension. This treatment was found sufficient to render most mild steels susceptible to failure at applied stresses that were below those which did not cause cracking with the material in the hot-rolled condition.

To make this part of the work more complete, experiments were carried out on steel 0·11/*B*/*K* to show the effect of various amounts of permanent strain with constant stress. Specimens were strained in varying degrees from 2%, the yield strain, to 14% permanent elongation on a 6-in. gauge length, and were stressed to one of the stress values, 27·3 or 24·0 tons/sq. in., before being corroded, with the results shown in Fig. 4.

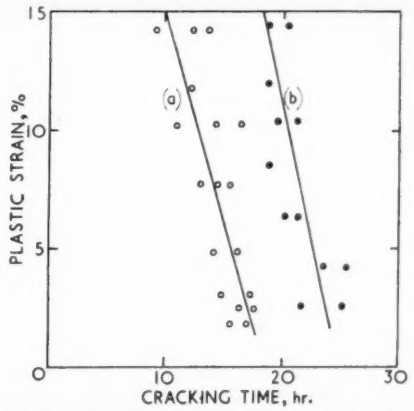

Fig. 4—Influence of various amounts of plastic strain on cracking time: (*a*) 27·2 tons/sq. in.; (*b*) 24 tons/sq. in.

The curves show that the amount of strain to which a specimen is subjected is not of paramount importance, although increasing amounts of strain apparently lower the resistance of the steel slightly.

Influence of Composition of Normal Commercial Steels on Cracking Susceptibility

Tests have been carried out on a wide range of commercial mild steels to determine whether any are completely resistant to nitrate cracking. The results on welded test plates[8] show that these steels may vary markedly in their proneness to stress-corrosion, but that none is completely resistant. These results have been partly confirmed in the tests on strip

Table II

CORRELATION BETWEEN CARBON CONTENT AND NUMBER OF CRACKS OBSERVED IN A BUTT-WELD TEST PLATE

Carbon, % (X)	$X-\bar{X}$	$10^4(X-\bar{X})^2$	No. of Cracks (Y)	$Y-\bar{Y}$	$(Y-\bar{Y})^2$	$10^2(X-\bar{X})(Y-\bar{Y})$
0·07	−0·09	81	33	23	529	−207
0·09	−0·07	49	30	20	400	−140
0·08	−0·08	64	25	15	225	−120
0·11	−0·05	25	15	5	25	−25
0·11	−0·05	25	10	0	0	0
0·16	0	0	13	3	9	0
0·09	−0·07	49	12	2	4	−14
0·10	−0·06	36	7	−3	9	18
0·22	0·06	36	8	−2	4	−12
0·18	0·02	4	5	−5	25	−10
0·18	0·02	4	5	−5	25	−10
0·22	0·06	36	5	−5	25	−30
0·22	0·06	36	2	−8	64	−48
0·165	0·005	0·25	2	−8	64	− 4
0·175	0·015	2·25	2	−8	64	−12
0·16	0	0	1	−9	81	0
0·235	0·075	56·25	1	−9	81	−67·5
0·265	0·105	110·25	0	−10	100	−105
$\bar{X}=0·16$		614·0	$\bar{Y}=10$		1734	−822

$$\text{Correlation Coefficient } r = -\frac{822\times10^{-2}}{\sqrt{(614\times10^{-4}\times1734)}} = -0·80$$

(For 18 pairs of observations r is significant if it exceeds 0·468).

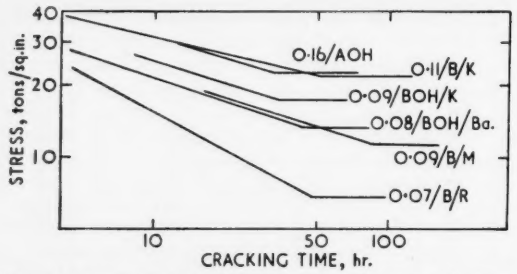

Fig. 5—Stress/cracking-time curves of steels of different compositions

specimens, although a few of the more resistant steels have not failed under these conditions of testing, even when previously severely cold-worked.

The results of the tests on steels that gave positive results in the experiments using the stressing jigs are shown in Fig. 5. The logarithmic plot accentuates the values of the lower limiting stresses below which failure does not occur. In all these tests, except those on steels 0·07/*B*/*R* and 0·09/*B*/*M*, the materials had to be cold-worked by straining in tension before cracking could be produced. With steels 0·18/*BOH*, 0·18/*BOH*/*K*, 0·22/*BOH*, and 0·22/*BOH*/*K*, however, even this procedure did not produce results definite enough to be shown in Fig. 5. Thus, in the case of steel 0·18/*BOH*, cold-working and the application of a stress of about 25 tons/sq. in. caused failure in two of the three specimens tested after 110 and 450 hr. respectively ; specimens tested at higher stress levels did not fail in 1000 hr. Similar tests on the other three steels, extending up to applied skin stresses of 35 tons/sq. in., produced no cracking during testing periods extending over 2000 hr.

When the compositions of the materials tested are examined in relation to the corrosion results, the carbon content of the steel appears to exert some influence : this is shown by the calculation of correlation coefficients (*see* Table II). In the experiments using strip test pieces, the threshold stress has been used as an index of the cracking susceptibility of the steel. The results previously published[8] on welded test plates have been subjected to a similar treatment : in this case the number of macro-cracks appearing in a 12 in. × 10 in. plate, made by butt-welding two 12 in. × 5 in. plates together, after 250 hr. immersion in the boiling nitrate solution, has been used as a measure of the corrosion susceptibility. Such a procedure is questionable, because it takes no account of the difference in size of cracks, or that the presence of one crack reduces the probability of others occurring. A better criterion of cracking susceptibility would have been the time required for the appearance of the first crack, but unfortunately, in some of the early experiments, no attempt was made to observe this. When the number of cracks apparent after 250 hr. is compared with the initial cracking time, where the latter is known, a simple relationship is obvious.

The correlation of the carbon content of the steel and its threshold cracking stress results in a coefficient of 0·93 (for the number of pairs of observations used, the value is significant if it exceeds 0·623). In this calculation, it has been assumed that steel 0·18/*BOH* had a threshold stress of 25 tons/sq. in., which was the value of the stress applied to the only specimens in which failure occurred. Similarly, steels 0·18/*BOH*/*K*, 0·22/*BOH*, and 0·22/*BOH*/*K* have been given values of 35 tons/sq. in., the highest stress at which tests were carried out. This assumption may be open to objection, but it is based upon the fact that these steels are susceptible to stress-corrosion cracking, as shown by the tests on welded plates, and that the value must be of this order, from a consideration of the maximum stress that the materials can withstand.

The two sets of results from the tests on welded plates and strip specimens seem to agree in showing an increasing resistance to stress-corrosion cracking as the carbon content of the steel is increased.

Attempts to relate the nitrogen contents of the steels and corrosion resistance, according to the recently advanced theory of Waber and McDonald,[18] have not indicated the same high degree of correlation shown by their work. The nitrogen factor, calculated as an atomic percentage from the formula previously given, and the number of intergranular cracks observed in a butt-weld test plate subjected to the nitrate test, are shown for a number of steels in Table III.

The correlation coefficient for these results is only 0·58, which is insignificant compared with 0·924, obtained by Waber and McDonald in applying their theory to the results of Athavale and Eilender.[23]

The beneficial effect of killing the steel with aluminium, reported by Waber and McDonald, is not readily apparent in the present results, nor does titanium appear to have any influence, when the results of tests on steels 0·18/*BOH*, 0·18/*BOH*/*K*, 0·22/*BOH*, and 0·22/*BOH*/*K* are considered. The fact that steels of Bessemer origin are more prone to cracking than O.H. steels would seem to be borne out by the present work, but it should be remembered that the Bessemer process is usually used in making mild steels of lower average carbon content than the O.H. process, and the effect may be related to this.

Effect of Wet Hydrogen Treatment

The work of Waber and McDonald[18] has shown that steels heat-treated in moist hydrogen, which reduces the carbon to 0·003% and nitrogen to 0·0036%, lose their initial susceptibility to stress-corrosion in the nitrate test. Since their work did not include a study of the effect of intermediate treatments, *i.e.*, those designed to reduce carbon and

Table III

THE NITROGEN FACTOR OF SOME OF THE STEELS TESTED

Steel No.	Nitrogen Factor	No. of Cracks in Butt-Weld Test Plate
0·07/*B*/*R*	140	33
0·09/*B*/*M*	25	30
0·08/*BOH*/*Ba*	−36	25
0·11/*B*/*K*	2	15
0·09/*BOH*/*K*	19	12
0·18/*BOH*	−7	5
0·18/*BOH*/*K*	−211	5
0·22/*BOH*	−32	2
0·16/*AOH*/*K*	−14	1

nitrogen without eliminating them, this has been studied in the present work by progressively altering the compositions of steels 0·07/*B*/*R*, 0·18/*BOH*/*K*, and 0·22/*BOH*.

The alteration in the structure and composition of the steels which accompanies wet hydrogen treatment does not occur uniformly through the thickness of the specimen, the reaction being more concentrated in the surface layers, particularly during the early stages. Thus, with treatments lasting for only 1 hr., a microscopic examination of a cross-section of the strip always shows the surface layers to be depleted of carbide, while the interior shows no change in structure. Such variations gradually disappear as the treatment is prolonged, the pearlite becoming divorced, and the carbide later spheroidized and evenly dispersed, as the carbon content falls to low values.

This variation in structure and composition makes a quantitative assessment of the degree of decarburization difficult, since, although the crack begins at the surface, it is later propagated through the higher carbon interior. The technique finally adopted consisted in taking drillings through the whole of the thickness of the specimen and determining the average carbon content of the specimen. With the low-carbon steel, and after prolonged hydrogen treatment of the higher-carbon steels, this value will be representative of the whole cross-section, but, in other cases, it merely represents a value between the minimum carbon at the surface and the maximum in the centre of the specimen.

The results of the tests on steel 0·07/*B*/*R* are shown in Fig. 6. In these and all subsequent experiments, unless a statement is made to the contrary, the specimens were cold-worked by elongating 10% in a tensile testing machine, and stressed to a skin stress of 20 tons/sq. in. during corrosion.

The results show that the treatment has little effect until the carbon content falls to a value approaching that of the maximum solubility of this element in α iron. Thereafter, the corrosion cracking resistance increases rapidly as the carbon content is decreased, until failure no longer occurs when the carbon is reduced to about 0·02%.

The results of the tests on steels 0·18/*BOH*/*K* and 0·22/*BOH*, covering a wider carbon-content range, are shown in Fig. 7.

These were steels that could not be cracked in the form of strip test pieces ; yet, after a treatment in

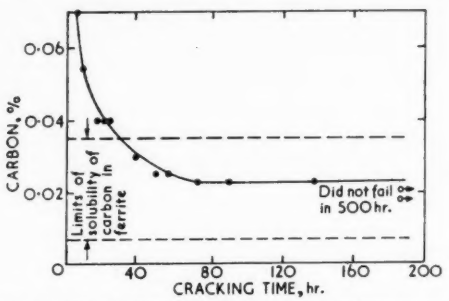

Fig. 6—Effect of decarburizing in wet hydrogen on the cracking time of steel 0·07/*B*/*R*

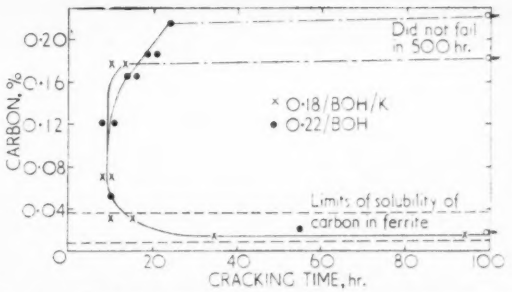

Fig. 7—Effect of decarburizing in wet hydrogen on the cracking time of steels 0·18/*BOH*/*K* and 0·22/*BOH*

moist hydrogen lasting 1 hr., with little reduction in the total carbon content, failure occurred in a very short time. Microscopic examination showed that the treatment had reduced the carbon to a depth of only two or three grains from the surface ; the structure further in was identical with that observed in the initial material, in which cracking could not be induced. Furthermore, the cracks were not restricted to the decarburized layer, but, having started there, they were propagated through the unaltered structure with equal speed. As the time of treatment was increased, the time before failure remained constant, until the limit of maximum solubility of carbon in α iron was approached, as in the previous case. From this point, the cracking time increased as the carbon was reduced, until immunity was again reached with a carbon content of about 0·015–0·02%.

In addition to the carbon analyses on the samples taken from the wet hydrogen test pieces, nitrogen determinations were made. These results showed a trend similar to those obtained when the effect of carbon content was considered in relation to cracking time. This, *per se*, might be interpreted as supporting the nitride theory of Waber and McDonald, but experiments reported in the next section, and the fact that very short moist hydrogen treatments cause a previously crack-resistant steel to fail, seem inexplicable on the nitrogen view.

By vacuum-annealing specimens at 700° C. after the moist hydrogen anneal, it was found that the occlusion of hydrogen has no significant influence on the corrosion mechanism.

Nitriding and Carburizing of Wet-Hydrogen-Treated and Other Steels

In view of the apparent discrepancy between the findings of the present work and those of Waber and McDonald concerning the influence of nitrogen in the stress-corrosion cracking of mild steel, an attempt was made to repeat some of their experiments.

In the first series of experiments, strips of two normally resistant steels, 0·18/*BOH*/*K* and 0·22/*BOH*, were nitrided for various times to produce a series of specimens with different nitrogen contents. The results of the tests on these specimens are shown in Table IV.

The results show that although the introduction of small amounts of nitrogen makes resistant steels susceptible to intergranular corrosion, the material

Table IV

EFFECT OF NITRIDING ON CRACKING OF THREE STEELS

Nitrogen, %	Cracking Time, hr.
Steel 0·09/*B*/*M*	
0·007	6
0·027	15
0·035	9
0·041	>250
0·052	>250
0·082	>250
Steel 0·18/*BOH*/*K*	
0·0035	>250
0·033	12
0·047	5
0·054	>250
0·078	>250
0·085	>250
Steel 0·22/*BOH*	
0·0045	>250
0·032	15
0·035	30
0·039	24
0·045	24
0·063	>250
0·087	>250
0·096	>250

becomes resistant again as the nitrogen content is increased. This result agrees with the findings of Athavale and Eilender.[23]

In a second series of experiments, one of the highly susceptible steels, 0·09/*B*/*M*, was treated in the same way as the two resistant steels, with the results shown in Table IV. The results show the same trend as those in the previous experiments, and again agree with the findings of Athavale and Eilender. This result has been explained by Waber and McDonald as being due to the fact that the nitriding treatment left the surface layers in a state of compression and so enhanced the resistance of the material. This explanation can hardly be valid in the present circumstances, since the specimens were given a high-temperature anneal after nitriding, and were then slowly furnace-cooled.

In a final experiment on the effect of nitriding on the cracking susceptibility of strip specimens, samples of steel 0·07/*B*/*R* were wet-hydrogen treated, to make them resistant to intergranular corrosion, before being nitrided prior to corrosion testing. The amount of carbon remaining in the material was 0·015% and the nitrogen introduced 0·095%, but the material failed to crack in a test extending over 300 hr.

To reinforce the evidence indicating the influence of the carbon content of the material in stress-corrosion cracking in the nitrate solution, a sample of high-purity N.P.L. iron was obtained and tested. The material was said to have a purity of at least 99·99%, so that the amount of carbon in the material could only be very small, and should in any case be in solution. The strip, measuring 6 in. × 1 in. × $\frac{1}{10}$ in., was cold-rolled to reduce it 20% before corrosion testing. After 300 hr. in the boiling nitrate solution, when the test was discontinued, the material still showed no signs of failure.

The strip was then subjected to a gas carburizing and homogenizing treatment, which introduced 0·14% of carbon. After further cold-rolling, the strip was again tested for 300 hr. in the corrosion bath, without any signs of cracking. It was thought that the reason for the material not cracking after carburizing might be connected with the fact that the carbide was present in the form of pearlite, which makes the material much more resistant than when the cementite is present in a globular form at the grain boundaries. Consequently, the sample was annealed at 700° C. for 72 hr., after which it was cold-worked, stressed, and subjected to the nitrate test again. Cracking was observed after only 1 hr. in the boiling nitrate solution, the crack propagating through the entire strip in a further 3 hr.

Influence of Subcritical Annealing on the Cracking Susceptibility of Resistant Steels

An examination of the effect of carbon in normal commercial mild steels suggests that the distribution of this element is important. Thus, low-carbon mild steels, which are the most susceptible to stress-corrosion, have the carbon present as grain-boundary carbide particles, whereas the more resistant materials have the carbide present in the normal pearlitic form. If, then, the attack upon the grain boundaries is associated with the presence of carbide particles in the latter, any treatments carried out on resistant materials that cause the carbide to migrate to the boundaries should make these susceptible to stress-corrosion. Prolonged annealing at about 700° C. causes pearlite to become divorced and later to spheroidize, some of the particles being within the grain boundaries. Two steels, 0·18/*BOH*/*K* and 0·22/*BOH*, were subjected to such annealing treatments for various periods, either *in vacuo* or packed in cast-iron turnings, with the results shown in Fig. 8.

The curves for the two steels are virtually coincident, and show that after a sufficiently long anneal, which, by microscopic examination, can be associated with the migration of some carbide to the grain boundaries, these initially resistant materials become susceptible to intergranular cracking, and, as the treatment is carried out for longer periods, failure occurs more readily.

Experiments on the Cathodic Protection of Steels

In experiments carried out on steel 0·09/*B*/*M*, cathodic potentials were applied to specimens that, in one series, were cold-worked and stressed to a skin stress of 27 tons/sq. in., and, in a second series, to 20

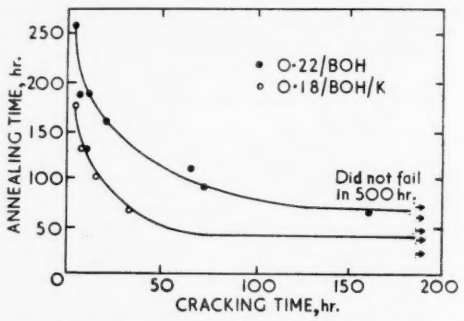

Fig. 8—Effect of subcritical annealing on the stress-corrosion cracking susceptibility of steels 0·18/*BOH*/*K* and 0·22/*BOH*

tons/sq. in. without cold-work. The results of these experiments are shown in Fig. 9.

The fact that the corrosion may be controlled by the application of an electrical current indicates the electrochemical nature of the corrosion process. The fact that different minimum applied currents are needed for complete protection in the two series of experiments seems to indicate that cold work and/or stress play an important part in the corrosion reactions.

Microstructural Studies of Stress-Corrosion Cracking of Mild Steels

In all the cracked specimens that have been microscopically examined in the present work, the path of the crack has always followed the grain boundaries. This is shown in Fig. 10, which is typical of the results observed.

When the microstructures of the steels are studied in relation to their proneness to cracking, an explanation of the effect of the carbon content is afforded. The most susceptible steels have the carbon present as grain-boundary cementite particles, as is usual in mild steels with carbon contents below 0·1%, and the increase in resistance to cracking as the carbon content is raised is accompanied by a decrease in the amount of boundary carbide, and a consequent increase in the number of pearlite grains. These facts are shown in Figs. 11 and 12.

The presence of boundary cementite in all steels that stress-corrode readily has also been shown by a microscopic study of steels subjected to wet-hydrogen treatment. Short treatments on resistant steels produce a susceptible condition in these materials, although the only structural change apparent is a slight amount of surface decarburization. Close examination of this layer shows the structure to be very similar to that observed in the highly susceptible low-carbon steels, in that the grain boundaries contain dispersed carbide globules. As the time of wet-hydrogen treatment is prolonged, the partly decarburized layer extends further into the strip, the surface structure remaining the same until the amount of carbon remaining is too small to be seen under the microscope. When the latter stage is reached, the cracking time begins to increase from the appreciably constant values associated with the presence of cementite in the grain boundaries of the surface layers.

One surprising feature associated with the effect of treatment in moist hydrogen is that although the structure in the interior of the strip is unaltered after short treatment, cracks, having formed in the decarburized surface, are readily propagated through the unchanged zone. It would appear from this that although cracks only form with great difficulty on surfaces having the carbon in the form of pearlite, they can readily be propagated through such structures once the crack is formed.

The microstructural alterations accompanying the promotion of susceptibility to stress-corrosion cracking when resistant steels are subcritically annealed also involve the migration of cementite to the grain boundaries. Such treatment causes the divorce of the pearlite initially, and, as the time of treatment is

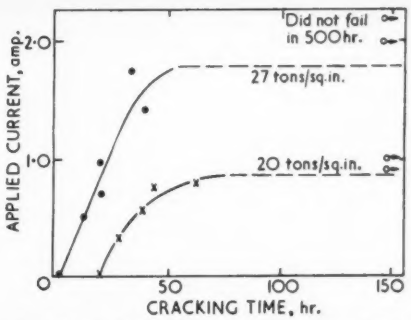

Fig. 9—Effect of applying cathodic potentials on the cracking time of steel 0·09/*B*/*M*

increased, the carbide becomes spheroidized and more evenly distributed throughout the ferrite, some of it appearing in the grain boundaries, as shown in Fig. 13.

Microscopic examination of the nitrided samples showed that, as well as adding nitrogen, the treatment decarburized the surface layers of the steel; hence, the fact that initially resistant materials crack after short nitriding treatments may be due to this decarburization rather than to the increase in nitrogen. The effect of longer treatments in cracked ammonia, although it again produced decarburization, also caused a surface concentration of nitride, as well as a large amount in the interior of the strips. All the steels that failed to crack after nitriding showed this surface concentration of nitride particles. The reason for its appearance at higher nitrogen contents and not at the lower values may be due to the fact that the homogenizing treatment used was not long enough when a fairly thick nitride case was produced. In any case, the results seem to substantiate the previous findings concerning the insignificant effect of iron nitride upon the stress-corrosion cracking of mild steel, since, if this were otherwise, it would be expected that there would be enough nitride in all these samples to cause ready failure.

A number of experiments have been carried out on polished and etched samples of mild steel, using the small jig for disc specimens, in an attempt to observe the way in which cracks formed during the corrosion process. This was done merely by removing the jig from the boiling nitrate solution at various intervals, rapidly washing and drying the specimen while still contained within the jig, and placing the whole under the microscope for examination of the stressed specimen.

The first stage after immersing the stressed specimen in the boiling nitrate solution seems to be the formation of a very thin oxide film, presumably the magnetite film observed by Wooster and Nockolds.[24] This extends over most of the surface, but is significantly absent in the region of most grain boundaries, and around many of the grain-boundary carbide particles. Grain-boundary attack can be seen shortly after this, the cracks often starting or ending at a boundary cementite particle. All these changes occur in a short time, not more than 2–3 min.; as the test proceeds, the oxide film seems to thicken, eventually becoming black in colour, and the attack upon the grain boundaries becomes more intense, until what

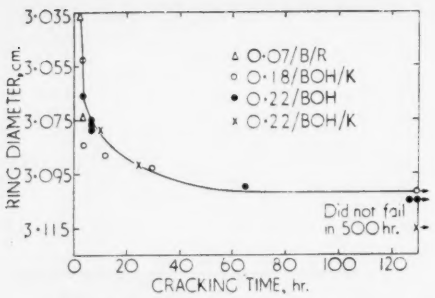

Fig. 16—Lattice distortion in various steels plotted against cracking time in nitrate test

may be called cracks appear in various regions. Thereafter, attack appears to be concentrated on those regions where the first cracks form, the latter developing while the attack diminishes elsewhere.

The outstanding feature of all the experiments in this part of the work is an indication of the part played by oxide films in the corrosion process. The observation that all regions in which attack begins are surrounded by a white halo when observed under the microscope, owing presumably to the ferrite being exposed at such points, is considered to indicate that such regions represent the local anodes in the corrosion process ; the cathodic regions are shown by the areas covered by the oxide film. The fact that boundary carbide particles, as well as the grain boundaries, were often seen to be surrounded by a white zone, appeared to indicate that such regions are inherently anodic to the body of the grain and that, if this is so, cracks will often start in such regions.

To discover whether such regions are, in fact, inherently anodic, or whether the effect is only seen when a stress is applied to a specimen, a polished and etched disc was subjected to corrosion without the application of a stress ; the result is shown in Fig. 14. The white halo surrounding some of the boundary carbide particles can clearly be seen, but not those that were normally situated in the region of grain boundaries when the specimen was stressed. The number of carbide particles surrounded by white areas also seems less than when the specimen is subjected to stress.

The results of the ' micro-corrosion ' tests on the higher-carbon steels, such as $0{\cdot}22/BOH/K$, were akin to those obtained on the highly susceptible steel $0{\cdot}07/B/R$, except that the oxide film was not so extensive. This was largely because it did not extend over the areas of pearlite and, consequently, was restricted to fairly small patches in the regions where only ferrite existed. As in the previous case, the pearlite areas, as well as being uncovered by the oxide film, were surrounded by a white ring, similar to the carbide particles in the boundaries of the lower-carbon steels. Where tests were made on these higher-carbon steels, actual crack formation was not often seen, although grain-boundary attack was noticed in widely dispersed areas.

If it is accepted that the oxide films indicate the cathodic regions on the surface, the remainder representing the local anodes, then the usually dangerous condition of small anodes and large cathodes, apparent in the low-carbon steels, does not obtain in the higher-carbon steels, where the area covered by the film is about equal to that left exposed.

A final experiment was concerned with the presence of micro-stresses remaining in the steel after cold-working and their possible influence in the corrosion process. This test was made towards the end of the work, when a theory to account for stress-corrosion cracking in mild steels was being formulated on the basis of micro-stresses in the steel having a considerable effect upon crack formation. On this view, confirmation should be possible by subjecting a piece of cold-worked steel to the corrosion test in the absence of an externally applied stress. It is well known that cold-working leaves micro-stresses in metals and, if these have a bearing on the corrosion process, cracking should, at least, start on the surface after plastic deformation.

For the test, a 6 in. × 1 in. × $\frac{1}{8}$ in. strip of steel $0{\cdot}07/B/R$ was polished and lightly etched on one surface, after which it was plastically extended by 10% by pulling in tension. The specimen was then immersed in the boiling nitrate solution without an external stress being applied. Examination under the microscope at various stages showed that the grain boundaries were being attacked and that, after about 3 hr. immersion, definite cracks were beginning to form. A photomicrograph of the surface at this stage, showing the slip bands left after the plastic deformation, is given in Fig. 15. The cracks shown did not develop into macro-cracks when the test was carried out for a much longer period, but it is considered that the test was effective in showing that micro-stresses are important, since a similar experiment on a sample that had not been cold-worked did not result in surface cracks appearing.

X-Ray Measurement of Micro-Stress in Corrosion Specimens

Mention has already been made of the fact that micro-stresses associated with the crystal structure of mild steel are thought to play some part in the stress-corrosion of this material, and also that an indication of the magnitude of such stresses may be obtained by the use of the X-ray technique. The value of the stress in the body of the grain, which will vary with the particular crystallographic direction considered, is proportional to the distortion of the lattice parameter, which, in turn, is proportional to the diameter of the reflected ring recorded on the X-ray film. The results, shown in Fig. 16, are quoted in terms of ring diameter.

The curve shows that a relationship between the lattice distortion within the material and its stress-corrosion cracking time exists, which is similar to that obtained between cracking time and externally applied stress for any one steel. Thus, when the lattice distortion does not exceed a limiting value, the material is unlikely to fail by stress-corrosion cracking. The results also seem to indicate a curve that is of general application, in that the points from which it is drawn represent steels of different compositions and in different states of heat-treatment.

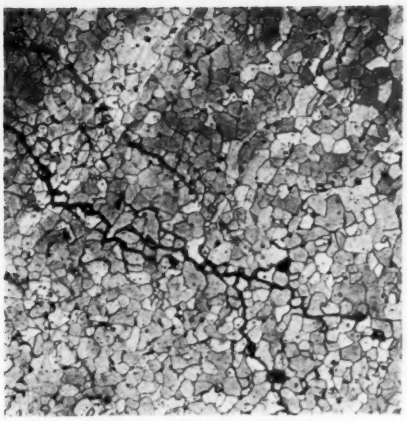

Fig. 10 — Stress-corrosion crack in mild steel, indicating the intergranular path followed × 100

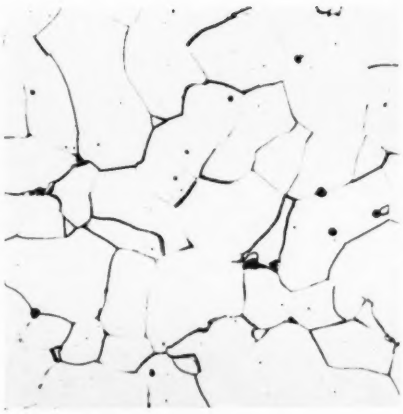

Fig. 11—Microstructure of a highly susceptible steel, 0·07/*B*/*R* × 500

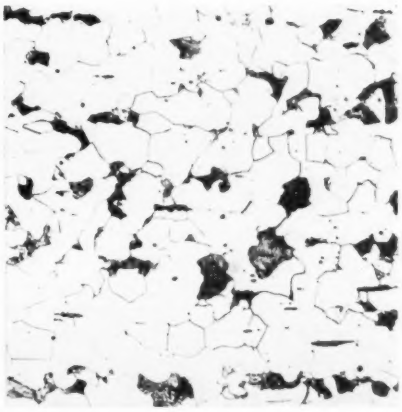

Fig. 12—Microstructure of a highly resistant steel, 0·22/*BOH* × 250

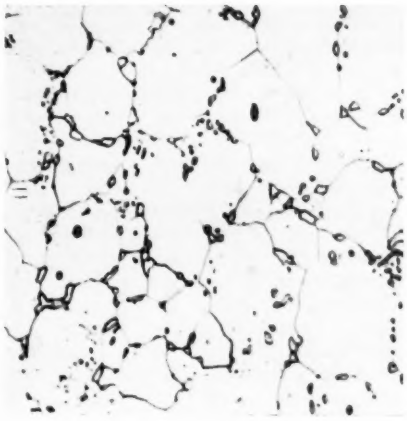

Fig. 13 — Microstructure of steel 0·22/*BOH* after annealing at 700° C. for 200 hr. × 1000

Fig. 14—Appearance of the surface of an unstressed specimen of steel 0·07/*B*/*R* after a short immersion in the corrosion solution × 1000

Fig. 15—Appearance of the surface of a cold-worked specimen of steel 0·07/*B*/*R* after 3 hr. corrosion × 1500

DISCUSSION

Influence of Applied Stress

A review of the literature on intergranular corrosion of mild steel indicates that most workers have contented themselves with an explanation of the influence of stress which amounts to the latter pulling open the grain boundaries and allowing the corrodant to reach the base of the crack to effect further attack. The fact that compressive stresses do not cause stress-corrosion cracks seems to be the reason for this explanation but, while the stress almost certainly does operate in this way, its influence is more fundamental than is indicated by the simple picture. Thus, on this basis, it is difficult to account for the fact that a definite threshold stress, below which failure does not occur, is observed in experiments where specimens are tested with different applied stresses. It would be expected that if the stress simply had pulled open the fissure produced by the initial corrosion, very small stresses would be effective in allowing propagation of the crack if the time allowed was long enough. There is no evidence from the present results, nor from similar results of previous workers, that even prolonged testing times are effective in producing cracking at stresses below the usually well-defined threshold value.

There is, however, further evidence that can be interpreted as indicating that the applied stress plays a fundamental part in the corrosion reaction that produces cracks. The fact that different steels have widely differing values of the limiting stress for failure again indicates an action that is more than merely widening the crack to allow further corrosion, since otherwise very similar stress/cracking-time curves would be expected for all materials. Furthermore, the results of the present experiments on the cathodic protection of material undergoing stress-corrosion would also seem to indicate the importance of stress in the corrosion mechanism.

Finally, the results of the short-time wet hydrogen treatments on the initially highly resistant steels $0{\cdot}18/BOH/K$ and $0{\cdot}22/BOH$, seem to show a fundamental effect from stress. Thus, the results indicate that if a crack can be started in the region of material that is normally very resistant to cracking, it can propagate with the same ease as in highly susceptible material. An explanation might be that, once a crack has formed, stress concentration occurs at its base to such an extent that the corrosion rate is greatly increased in this region. This explanation would appear to be substantiated in some degree by a recently published work[25] on intergranular cracking in mild steels subjected to attack by caustic soda. It was found that in this solution, failure could only be produced if notches were machined in the test pieces before testing. Certainly, the conditions of corrosion in caustic soda may be very different from those in the present work but, nevertheless, there is a suggested stress-concentration effect in these experiments, similar to that implied in the results just discussed.

The foregoing gives some evidence for the suggestion that the stress applied to specimens undergoing stress-corrosion not only opens up the crack so that further corrosion can occur at its base, but, also, that it plays an integral part in the corrosion reaction.

Influence of Structure and Composition

The primary feature resulting from this work is the influence that carbon has upon the cracking process. This result is substantiated by the findings of Athavale and Eilender,[23] whose results give a correlation coefficient of $-0{\cdot}82$ (values above $0{\cdot}4$ are significant for the number of results quoted). This correspondence between carbon content and stress-corrosion susceptibility has been noticed by other workers, but they have usually looked upon the result as fortuitous, because cracking was actually retarded as the carbon content was increased. Since the amount of boundary cementite in mild steels varies in exactly the same way as this, however, and since the region of the grain boundaries is important, the results seem to be very significant. Furthermore, the results of the wet-hydrogen treatment and sub-critical annealing experiments have also indicated that the distribution of the carbide is more important than the content, and that, in general, mild steels in which the carbide is in the form of particles situated within the grain boundaries are highly susceptible to intergranular corrosion. Finally, the experiment conducted on the N.P.L. high-purity iron seems to prove more conclusively that grain-boundary particles are necessary to produce a condition of susceptibility to stress-corrosion cracking.

This relationship having been demonstrated, the question arises whether it is cementite that is attacked by the corrosive solution, and the continuity of the grain boundary thereby destroyed. The microscopic examinations that have been carried out do not support such a view, since cracks can often be seen passing along the boundary between a carbide particle and a ferrite grain, with the carbide particle still intact. In addition, Waber and McDonald[18] state that thermodynamical calculation shows cementite to be slightly cathodic to ferrite, a fact that is confirmed by experiment.[26]

Thus, the weight of evidence indicates that, although grain-boundary carbide particles are an essential part of the structure of a susceptible mild steel, the particles themselves are not attacked by the corrosive liquid. This is taken to indicate that the ferrite in the region of the grain boundaries is the active material, and that it is somehow rendered active by the presence of cementite globules. Some other constituent in the region of the boundaries may cause the localization of the attack on the latter, but it is difficult to reconcile this view with the fact that only when the carbide is diffused to the boundaries in higher-carbon steels do they become readily susceptible to intergranular corrosion. The experiment on N.P.L. iron could not easily be explained by such a hypothesis, because of its extreme purity.

If ferrite is the constituent that suffers corrosion, an explanation must now be sought to account for its being attacked only when situated within the grain boundaries. The reason advanced is that micro-stresses or localized distortions exist in the region of the grain boundaries that are greater than those in the body of the grain, and, therefore, serve to make

this material less noble than when it is in the undeformed state.

Evidence for Presence and Influence of Micro-Stresses

The atomic structure where two grains meet is one in which the atoms occupy positions intermediate between the sites that would be occupied if the atom were situated on the normal space lattice of one or the other grain ; *i.e.*, a grain boundary is a region of transition from one grain orientation to the next.[27] Since the atoms in a boundary region are displaced from their normal positions in this way, the boundary must be a seat of localized distortion, and therefore such regions will be inherently anodic to the body of the grain.

There is some experimental evidence that the difference in electrode potential between grain boundaries and interiors, owing to the disorientation of adjacent grains, may be sufficient, in some cases, for grain-boundary attack to take place. The work of Lacombe,[28] on high-purity aluminium immersed in 10% HCl solution, has shown that when the difference in orientation between two grains is large, the common boundary suffers much greater attack than when the orientations are similar. More recently, Robertson[29] has considered the stress-corrosion of copper and its alloys from a similar point of view, and has suggested that a similar mechanism operates in these cases.

It seems unlikely, however, that attack in mild steels is so simple as in the cases mentioned, since pure iron is not susceptible to intergranular attack in the nitrate solution, and attack does not occur in the absence of stress. The experimental evidence, which points to the marked influence of cold work, stress, and grain-boundary carbide particles, indicates that these might operate by increasing the grain-boundary distortion, and, therefore, the difference in electrode potential between grains and boundaries, sufficiently for corrosion to occur.

The work of **László**[30] on tessellated stresses has shown that, owing to the difference in thermal expansions, a spherical cementite particle embedded in a ferrite matrix is the centre of a stress system which extends over a short distance, but which may reach a maximum value of 40,000 lb./sq. in. If the discontinuity in the ferrite matrix occupied by the cementite particle is exactly the correct size for the latter at, say, 700° C., no stress will exist at this temperature. As cooling occurs, however, the ferrite tends to contract more than the carbide, so that a hydrostatic pressure is developed in the ferrite. The value of this exceeds the yield stress of ferrite, so that the latter yields until a stress is left that can only be balanced by elastic distortion.

These calculations were based upon a particle embedded within the centre of a mass of ferrite, so that they are not strictly applicable to the present case, where the presence of carbide particles in the grain boundaries is important. The stresses developed in this case are, however, not likely to be very different from those for which the calculation was made, since the size of the particles is large compared with that of any discontinuities at the grain boundaries.

The effect of cold plastic deformation is also known to produce a system of micro-stresses or localized deformations in a polycrystalline aggregate. This is because the yield tensions of the crystals in an aggregate vary with the orientation, so that some grains plastically extend before others and impose stresses of an opposite sign on neighbouring grains. These stresses occur over sufficiently large distances to be detected by X-ray analysis, but, since only grains with certain orientations contribute to a given diffraction line, the lattice strain measured is not the mean strain in all the crystals, which should be zero, but the average of the strains in those crystals with particular orientations, which may be positive or negative.

Thus, the stresses that have been measured in the present X-ray work, which appear to have some relationship to the corrosion cracking susceptibility, are not those which cause the latter (assuming that micro-stresses cause the phenomenon), since they refer to stresses in the body of the grain. Hence, there would appear to be little to be gained from quoting the results in terms of stress. These stresses may, however, be related to the stresses in the transition lattice of the grain boundary, because, if the lattices of two adjacent grains are distorted in opposite directions, the transition atoms occupying boundary positions will have to move to new equilibrium positions, which will be determined by the distortions in the grains themselves.

Furthermore, the work of Nye[31] on silver chloride has shown that localized stresses are set up along the grain boundaries when an annealed sample is plastically deformed, and to a lesser extent when the stress is still within the elastic range.

The marked influence that the applied stress has on the stress-corrosion of mild steel is also to be expected from a consideration of the influence of micro-stresses. Thus, the addition of the applied stress to the tessellated stress associated with carbide particles must cause further plastic deformation in some regions of the latter at least, because the total stress exceeds the yield stress of ferrite. The elastic anisotropy of cubic crystals will also cause adjacent crystals of differing orientation to be elastically strained in varying degrees, and the grain-boundary structure distorted further, as indicated by the work of Nye.

The suggestion that the principal factors that operate to produce susceptibility to stress-corrosion in mild steel do so by producing grain-boundary distortion is therefore not unfounded. It is further suggested that the distortions in the boundaries must be balanced by distortions of opposite sign in the adjacent grains, and that measurement of the latter will give some indication of the former.

Suggested Mechanism of Stress-Corrosion Cracking in Mild Steels

The experimental evidence indicates that the following points require explanation in any theory of intergranular corrosion of stressed mild steel :

(i) The influence of applied stress
(ii) The effect of cold work in the presence and absence of applied stress
(iii) The influence of carbon content, as shown by the correlation between carbon and cracking tendency

in commercial steels ; the disappearance of cracking when the carbon is reduced to about 0·015% by wet-hydrogen treatment ; the susceptibility of initially resistant N.P.L. high-purity iron after the addition of carbon

(iv) The distribution of the carbide, as shown by the subcritical annealing experiments, and also, in some degree, by the wet-hydrogen experiments and the tests conducted on various commercial steels

(v) The ease with which a crack passes through regions with an initially resistant structure, once the crack has started elsewhere

(vi) The relationship between the lattice distortion, as measured by X-ray analysis, and the stress-corrosion cracking susceptibility.

Having regard to the above points, and also to some of the considerations of previous parts of the discussion, the mechanism of stress-corrosion crack formation is envisaged as follows :

A grain boundary is a region of inherent distortion, but the magnitude of the latter is increased when carbide particles are located within such regions and the material is cold-worked. The ferrite in the region of the carbide particles will be distorted to a greater extent than elsewhere, owing to the presence of so-called micro-stresses, and also to the concentration of plastic distortion in such regions when the material is plastically deformed. The extent of the distortion is sufficient to make the material anodic to the rest of the grain, so that the localized corrosion takes place ; this will be very severe, because of the small area of the crack in comparison with the cathode area. The small pit formed by the corrosion concentrates the applied stress in the region of its base, and this stress increases the potential difference between the base of the pit and the cathodic grain interiors. If the newly exposed region is not already sufficiently distorted by previous cold work or the presence of a nearby carbide particle, the distortion accompanying the stress concentration moves the potential to a sufficiently anodic value for further corrosion to take place. The crack may thus be propagated over the resistant region to the next region of distortion.

In other words, it is suggested that mild steels, when in a condition in which they are susceptible to stress-corrosion cracking, have an almost continuous film of distorted ferrite in the grain boundaries, which is sufficiently anodic and small in extent, compared with the rest of the surface, to cause intense corrosive attack in such regions.

CONCLUSIONS

The results of other workers, emphasizing that cracking occurs when a minimum stress is exceeded, and that previous cold plastic deformation is detrimental, have been confirmed. An examination of the stress-corrosion-cracking susceptibilities of a number of steels with respect to their compositions shows that the ' nitride theory ' of Waber and McDonald is not of general application, but that the most important element associated with the cracking is carbon. Experiments using steels synthesized by the addition of carbon or nitrogen to pure iron have suggested that the distribution of the carbide, rather than its total amount, is important, and this has been partly confirmed by altering the distribution of the carbide. The cracking is associated with the presence of cementite in the grain boundaries of the ferrite.

Intergranular corrosion of mild steel under the given conditions is due to the presence of carbide particles in the grain boundaries, plastic deformation, and the application of stress to the metal during corrosion, which all increase the inherent distortion in the transitionary structure of the grain boundaries. This distortion makes the grain boundaries sufficiently less noble than the grain ' interiors ' for corrosion to be concentrated in these regions.

The theory that is offered to account for the phenomenon is similar to that suggested for corrosion-fatigue in mild steels. This is preferred to one based on strain-ageing and the precipitation of an anodic phase within the grain boundaries, similar to the ' Generalized Theory ' of Dix, which does not account for all the results mentioned ; when the strain-ageing propensities of the materials tested were determined, there was no correlation with stress-corrosion cracking.

It is hoped to continue the present work to include studies of other solutions that are known to cause intergranular corrosion in mild steel.

Acknowledgments

The author wishes to record his thanks for much fruitful discussion and advice to present and former colleagues, notably Mr. C. E. Pearson, former Professor of Metallurgy at the University of Durham, for his constant interest and encouragement ; Dr. E. C. Ellwood, for his help in the design of the X-ray equipment ; and Professor A. Preece for the facilities provided. In addition, it would have been impossible to carry out the work without the assistance of the following : Redheugh Iron and Steel Co., Ltd. ; Consett Iron Company, Ltd. ; Appleby-Frodingham Steel Co.; and Stewarts and Lloyds, Ltd.

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HISTORICAL NOTE NO. 29

The Old Blast-Furnace at Maryport, Cumberland

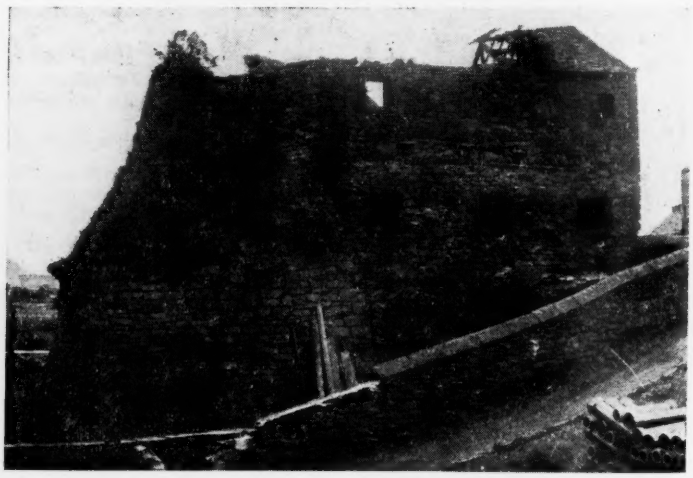
By Dr. H. R. Schubert

THE blast-furnace at Maryport was erected in 1752. It was built of red sandstone, the inner cavity being lined with brick. The capacity was about 2700 ft. The furnace was operated until 1783, but apparently not later.*

The remnants of the blast-furnace are still standing. It is a typical eighteenth-century English furnace, similar in construction to the blast-furnace at Staveley, in Derbyshire, described by Pilkington in 1789 and illustrated by a side elevation of the building.†

In front of the blast-furnace at Maryport was the casting house which is now destroyed. At the rear is the charging or bridge house, the top floor of which served as a room for storing ore, fuel, and flux ready to be charged into the 'mouth' of the furnace. The lower floor served as a dwelling for the 'filler' who was responsible for the charge.

The roof of the charging house has fallen in and, as shown in the accompanying photograph, a large crack is visible in the side of the furnace. There is a great danger of the crack widening, so that the whole building will soon fall to pieces if left in its present state. It is greatly desirable that means should be found to preserve this monument of the Age of the Industrial Revolution which laid the foundations to Britain's industrial greatness.



Manuscript received 9th June, 1952. Dr. Schubert is Historical Investigator to The Iron and Steel Institute.

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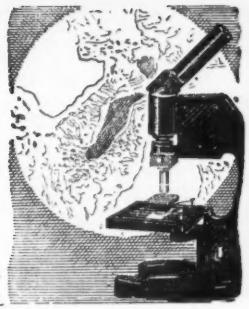
BRITISH IRON AND STEEL RESEARCH ASSOCIATION



The Quench-Ageing of Iron

By Anna L. Tsou, M.Sc., Ph.D., J. Nutting, M.A., B.Sc., Ph.D., and J. W. Menter, M.A., Ph.D.

SYNOPSIS

Optical and electron microscopes have been used to follow the metallographic changes occurring during the precipitation of carbon from a supersaturated solid solution in α-iron over a range of ageing temperatures and times. An attempt has been made to identify the precipitates by electron diffraction methods. The results obtained show that precipitates form at random throughout the grains and then grow preferentially at the sub-grain boundaries; at this stage they have the structure of ε-iron carbide and are plate-like in shape. After ageing at 300° C., the precipitates are still plate-like in shape but have the normal cementite structure. Ageing at still higher temperatures results in preferential growth at the ferrite grain boundaries, and eventually cementite films are formed. The sequence of changes is very similar to that—previously deduced from X-ray evidence—for the decomposition of martensite.

Austenite has been detected as a grain-boundary film, formed after quenching from 700° C. an iron containing 0·026 wt.-% of carbon. Some of the factors responsible for its formation have been investigated.

Introduction

THE quench-ageing of iron has been studied by many workers during the past 20 years, and there has been general agreement that both carbon and nitrogen, because of their decreasing solid solubility in ferrite with decreasing temperature, are the elements responsible for ageing. The published equilibrium diagram for the iron–carbon system[1] shows the solubility of carbon in α-iron to be 0·025 wt.-% at 723° C., the eutectoid temperature, and 0·006 wt.-% at 0° C. A more recent determination of the solubility of carbon in α-iron at the eutectoid temperature has been made by Stanley,[2] who obtained a value of 0·018%. The solubility at lower temperatures has been investigated by Wert.[3] From internal friction measurements, he found the solubility at 150° C. to be of the order of 4×10^{-5} % and, by extrapolating the linear relation between the logarithm of the concentration and the reciprocal of the temperature, he found the solubility at 20° C. to be about 10^{-7} %. It is possible, therefore, to retain carbon in supersaturated solid solution by quenching a saturated solid solution from the eutectoid temperature; on heating the supersaturated solid solution, precipitation occurs, which brings about various changes in the properties of the iron. However, in view of the small amounts of the element involved, direct evidence of the mechanism of precipitation is not easy to obtain; thus, indirect methods of investigation have chiefly been used.

Davenport and Bain,[4] on the evidence of hardness measurements, claimed that quench-ageing resulted from the precipitation of cementite from a supersaturated solid solution of carbon in α-iron. They showed that the maximum hardness attained decreased with increasing ageing temperature, a characteristic of quench-age-hardening systems. They also found that decarburized iron did not age-harden.

The decreasing solid solubility of nitrogen in α-iron has been reported by Bean,[5] Sawyer,[6] and Fry,[7] who suggested that iron–nitrogen alloys should age-harden. Later Dean, Day and Gregg[8] demonstrated the expected hardening, which they suggested was due to the precipitation of iron nitride.

More detailed information on the quench-ageing process has resulted from measurements of internal friction. Snoek[9] showed that the internal friction

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peak found in iron, at a temperature dependent upon the frequency of oscillation of the specimen, could be traced to the presence of carbon or nitrogen in solid solution in α-iron. Dijkstra[10] investigated this effect further, and found that the magnitude of the peak was proportional to the amount of carbon or nitrogen in solid solution. He then followed the precipitation of carbon and nitrogen from supersaturated solid solution in α-iron by following changes in the magnitude of the internal friction peak after differing ageing treatments. It was concluded that the precipitation of carbon was a single-stage process, whereas nitrogen precipitated by a two-stage mechanism. Dijkstra was able to follow metallographically the precipitation of nitrogen from supersaturated solid solution in ferrite, and he concluded that the second stage corresponded to the formation of Fe_4N, but he was unable to identify the first-formed precipitate.

Wert[11] examined in greater detail the precipitation of carbon and nitrogen from supersaturated solid solutions in α-iron, using internal friction measurements. From his results, Zener[12] was able to determine by calculation the shape of the precipitates. He concluded that carbon precipitated as spheres of Fe_3C, whereas nitrogen formed plates of unknown composition, which subsequently changed to Fe_4N. When examining the decomposition of nitrogen martensites by X-ray diffraction methods, Jack[13] observed the appearance of a new phase, which he designated α″. The structure was that of an ordered interstitial distribution of nitrogen in a distorted ferrite lattice, the ideal composition being $Fe_{16}N_2$. Jack suggested that the α″ phase could be the unidentified phase reported initially by Dijkstra.[10]

By electron microscopic examination of suitably aged specimens, Radavich and Wert[14] attempted to check Zener's conclusions on the precipitation of carbon. Their evidence, based on a single experiment —*i.e.*, the ageing of a supersaturated solid solution of 0·015% of carbon in α-iron at 300° C. for 25 min.— was claimed to support the theory of spherical carbide precipitates.

Trotter, McLean, and Clews[15] have investigated, with the aid of the electron microscope, the structures obtained on quenching from 690° C. a carburized iron containing 0·70% of carbon. They found that the ferrite grains showed plate-like precipitates, which were thought to be carbides. These facts do not agree with the conclusions of Zener[12] or the experimental results of Radavich and Wert.[14] Thus, it was thought that a more complete investigation of the ageing phenomena was required, in view of the discrepancies between the results of previous workers.

In the present investigation, the precipitation of carbon from a supersaturated solid solution in α-iron has been followed by metallographic examination of quenched and aged specimens of ingot iron. An attempt has also been made to identify the nature of the newly formed precipitates by electron diffraction.

PREPARATION OF SPECIMENS

The material used was an ingot iron having the following analysis:

B.I.S.R.A. Specification No. ADB

C, %	0·026	W, %	<0·02
N, %	0·0057	V, %	<0·01
Si, %	<0·02	Ti, %	<0·02
Mn, %	<0·05	Co, %	<0·02
S, %	0·035	Cu, %	<0·05
P, %	<0·004	Al, %	<0·005
Ni, %	0·038	Sn, %	<0·02
Cr, %	0·01	Pb, %	<0·02
Mo, %	<0·01		

To avoid the risk of the formation of austenite from the carbon in excess of that soluble in ferrite at 723° C., the specimens for the present investigation were heated at 700° C. for 2 hr. prior to quenching into iced water. With this treatment, 0·015% of carbon was retained in supersaturated solid solution. After quenching, the specimens, in the form of ½-in. cubes, were aged at temperatures of 100, 200, 300, 400, 500, and 600° C., respectively, for different periods of time. The structural changes induced by ageing were observed metallographically, using both the optical and electron microscopes.

A standard mechanical polishing technique was used to give the initial polish. The final surface to be examined was obtained after repeated etching in 2% nital and polishing with fine magnesium oxide powder on a Selvyt cloth. The final etch was kept constant at 40 sec. in 2% nital. Although electropolishing is usually considered to be superior to mechanical polishing, it was found that the former often produced spurious effects; these were thought to be a result of the large number of oxide inclusions in the material. Thus, electropolishing was not generally used.

Formvar replicas, deposited from a 2% solution of the plastic in dioxane, were dry-stripped from the etched specimens and examined in the Siemens electron microscope, which was operated at 70 kV.

METALLOGRAPHIC EXAMINATION

Samples of the ingot iron were first examined in the as-received condition, when a marked veining structure was observed (*see* Fig. 2*a*). This could be removed by heating the specimen at 900° C. for 4 hr. and slowly cooling in the furnace, when the resulting structure was that of equi-axed ferrite grains with precipitates at the grain boundaries. Across some of the ferrite grains were fine line markings, which will in future be referred to as sub-grain boundaries. A typical microstructure is shown in Fig. 2*b*. This pretreatment was essential, otherwise the vein markings would have masked any later metallographic changes.

After giving the specimen a solution treatment at 700° C. for 2 hr. and quenching into water, most of the particles situated at the grain boundaries had disappeared. This clearly indicated that the particles must have redissolved at the temperature of 700° C. or less, and that they were held in solution after quenching. The sub-grain boundaries were unchanged. (*See* Fig. 2*c*.)

The microstructural changes induced by the ageing treatments are described below under the different ageing temperatures.

Ageing at 100° C.

Hardness measurements were obtained after suitable intervals of ageing. The hardness increased

gradually, reached a maximum after 60 min., and then fell again at the same rate to the original value, at which it remained almost constant for a further 20 hr. of ageing (*see* Fig. 1).

No change in the microstructure was detected until the maximum hardness value was reached, when a mottled background structure was revealed by etching. Figure 3*a* shows the specimen after ageing for 60 min. Two of the three adjacent grains shown in the micrograph are noted to have a mottled appearance, whereas the remaining one is quite free from structure. (The large particles at the junction of the grain boundaries are oxide inclusions.) This variation from grain to grain was general over the specimen surface. Formvar replicas, stripped from the mottled regions, were examined in the electron microscope, where they showed a structure of diffuse asperities. By shadowing the replica at 45° C. with Au–Pd (60/40) alloy, it was possible to estimate that the asperities were of 300–500 Å. dia. An electron micrograph is shown in Fig. 3*b*.

No major change of the optical microstructure was found after ageing for 5 hr., but the mottled appearance had become more pronounced and had spread over the whole surface; no grains free from such an appearance could be detected. Figure 3*c* shows the typical effect. After ageing for 16 hr., distinct particles were observed even under the optical microscope. The precipitated particles were not spherical but elongated, being sharply defined on one side but merged into the background on the other. This suggests that the particles are platelets or discs. The dimensions of the discs were estimated to be about 500 Å. thick and 2000–3000 Å. dia. Figures 4*a* and *b* show the corresponding optical and electron micrographs.

Ageing at 200° C.

The hardness of the aged specimen increased rapidly during the first 5 min. of treatment. After 5 min. the hardness fell rapidly again to a value much below the initial one and became constant after two hours' ageing (*see* Fig. 1).

The microstructure of the specimen, as a result of ageing for 5 min.—that is, at the peak of the hardness curve—showed a mottled structure similar to that of the specimen aged for 60 min. at 100° C. (also at the peak of the hardness curve). No estimation of the particle size was made, owing to the diffuseness of the particle outlines, but it can be safely considered to be of the same order as that found in the specimen aged at 100° C.

The sequence of changes on further ageing consisted of a general coarsening of the mottled structure until eventually particles were visible with the optical microscope. Precipitation did not take place at a uniform rate in all the grains, but where precipitates were visible they were uniformly distributed within individual grains. Eventually, preferential growth of the particles at the sub-grain boundaries occurred, giving the structure shown in Fig. 4*c*. The corresponding electron micrograph is shown in Fig. 4*d*. The precipitated particles were plate-like in shape, with dimensions about 2500 Å. thick and 7–10,000 Å. dia. The mean volume of the precipitated particles formed after

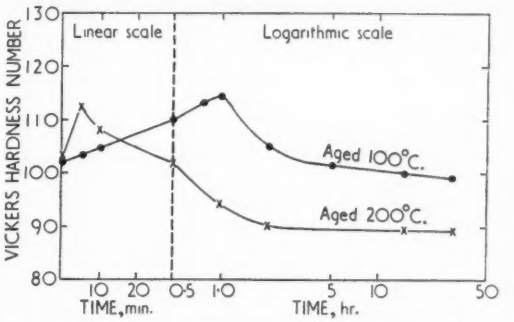

Fig. 1—Effect of ageing time and temperature upon hardness

15 hr. at 200° C. is about 30–40 times greater than the volume of those formed after ageing for 16 hr. at 100° C.

Ageing at 300° C.

No hardness measurements were carried out, owing to the rapid change of hardness at 300° C., but the ageing process was followed metallographically. Particle formation was completed after ageing for 30 min., and then the size and the number of the precipitates remained approximately constant even after ageing for 22 hr. No mottled stage could be detected; this was probably due to the rapid transformation of the structure at the higher temperature. The microstructure was generally similar to that found after ageing for prolonged periods at 200° C., the precipitates retaining their plate-like shape. The optical micrograph is shown in Fig. 4*e*.

Ageing at 400° C.

Precipitated particles were observed after ageing for 30 min. at 400° C. The particles were distributed within the grains and at both the grain boundaries and sub-grain boundaries, but they still retained their plate-like shape. With further ageing for 1–16 hr., preferential growth of the particles at the grain boundaries occurred and, consequently, fewer particles were present within the grains. After ageing for 20 hr., all the particles within the grains had disappeared.

Ageing at 500° and 600° C.

On increasing the ageing temperatures beyond 400° C., the particles precipitated at random throughout the grains, then grew preferentially at the sub-grain boundaries and eventually at the grain boundaries. The particles at the grain boundaries, after ageing for 20 hr. at 500° C., were no longer plate-like in shape but resembled the normal cementite particles found in tempered steels. After ageing at 600° C., further growth of the particles at the grain boundaries occurred, resulting in the formation of grain-boundary films, particularly at the junction of three grains.

ELECTRON DIFFRACTION STUDIES

The identification of precipitated phases is often difficult; the results obtained are unconvincing when using microscopic techniques alone, and in the many instances when the concentration of the precipitated

Table I

RING RADII AND CORRESPONDING LATTICE SPACINGS FOR IRON QUENCHED FROM 700° C.

Ring Radius, cm.	Intensity	Lattice Spacing, kX	α-Fe*	γ-Fe†	Fe_3O_4
Spotty Rings					
1·31		2·04	2·05		
1·84		1·45	1·43		
2·28		1·172	1·16		
2·93		0·912	0·910		
3·46		0·772	0·757		
3·93		0·68	0·665		
Strong Rings					
1·27	VS	2·10		2·10	
1·47	S	1·816		1·815	
2·08	S	1·283		1·284	
2·43	S	1·097		1·094	
2·56	W	1·042		1·048	
3·21	MS	0·833		0·833	
3·31	MS	0·808		0·812	
3·62	W	0·739		0·742	
3·82	W	0·699		0·699	
4·38	W	0·609		0·606	
Other Rings					
0·89	WD	3·00			2·98
1·07	W	2·50			2·54
1·66	VW	1·61			1·612
1·81	W	1·47			1·477

* A.S.T.M. X-ray index
† Calculated from $a_0 = 3·63$ kX.
VS = Very strong
S = Strong
MS = Medium strong
W = Weak
VW = Very weak
WD = Weak diffuse

phase is very small, it is impossible to use X-ray methods.

These difficulties were overcome in the present work by using the electron diffraction technique in close conjunction with the electron microscope. Electron diffraction patterns obtained by reflection arise from electrons transmitted through surface asperities. Thus, the protruding precipitated particles that occur on etching the aged ingot iron are possible diffracting regions.

The electron diffraction camera used was of the Finch type, operated at 45 kV. with a camera length of 50 cm. The angle of incidence of the electron beam was about 1°.

The method of preparation of the specimen surface was the same as that used for metallographic examination; *i.e.*, mechanical polishing, followed by etching for 40 sec. in 2% nital. The freshly prepared specimens were immediately inserted in the camera, to minimize oxidation of the surface. A thin oxide film was probably formed during etching, but this did not noticeably obscure the diffraction pattern from the underlying material.

The Quenched Condition

To determine the composition of the constituents appearing as precipitates on ageing, a specimen freshly quenched from 700° C. was first examined. The observed rings were in three groups: the first, a set of spotty rings which corresponded to α-iron; the second, a rather weak group which could be attributed to the strongest lines of iron oxide (either γ-Fe_2O_3 or Fe_3O_4); and the third, a group of very strong rings which fitted closely to a face-centred cubic structure with $a_0 = 3·63$ kX. These results have been reported briefly elsewhere.[16] The ring diameters and corresponding interplanar spacings are shown in Table I. (The diffraction photograph is shown in Fig. 5*a*.) The mean error of the interplanar spacings derived from the ring radii is about ± 1%.

The spotty α-iron rings result from only a few ferrite grains being irradiated by the electron beam, but the total number of ferrite grains in the area of the specimen irradiated is much larger than would be deduced from the diffraction photograph. However, with an incident angle of 1°, a surface asperity shades a region from the electron beam of 60 times its own height, and it is thought, therefore, that the surface asperities prevent many of the ferrite grains from being irradiated; the nature of the asperities will be discussed later. The iron-oxide rings may be formed by diffraction from either an oxide film on the metal surface or the oxide inclusions within the metal, but in view of the diffuseness of the rings, the former is the more likely source.

The face-centred cubic structure corresponds with that of an austenite. The actual lattice spacing of austenite depends upon the amount of carbon or nitrogen in interstitial solid solution. The measured values[17–20] range from 3·56 kX. with no carbon or nitrogen to 3·64 kX. with 1·7% of carbon or 2·33% of nitrogen. In view of the errors of measurement of the ring radii in the diffraction photograph, the carbon or nitrogen contents found in the quenched specimen could range from 0·85 to 1·7% of carbon or 1·17 to 2·33% of nitrogen. Hence, the pattern will be referred to as that of an austenite rather than γ-iron, thus implying that carbon or nitrogen or both are present in solid solution.

Electron microscopic examination of replicas stripped from the quenched specimens revealed that the material at the boundaries of the ferrite grains was raised above the general level of the surface; *i.e.*, the boundaries formed ridges rather than the grooves normally associated with the microstructures of pure metals. Trotter, McLean, and Clews[15] observed ridges within ferrite crystals, and concluded that they were carbon-rich but not necessarily of composition Fe_3C.

By stripping preshadowed replicas from the quenched specimens and using the technique outlined by Agar and Revell,[18] it has been possible to measure the height of the grain-boundary ridges above the adjacent ferrite grains. The values obtained after etching for 40 sec. were of the order of 3000 Å. As the ridges are the only surface asperities other than the oxides, it would appear that they are responsible for the austenite pattern and the shielding effect on the ferrite grains.

It is surprising, in view of the treatment given, that austenite is present in the specimen. To investigate this effect further, two specimens were heated for 2 hr. at 650° and 600° C. respectively, and water-quenched. In both of these specimens austenite was detected. However, a specimen quenched from 700° C. and examined after abrading on 000 emery showed

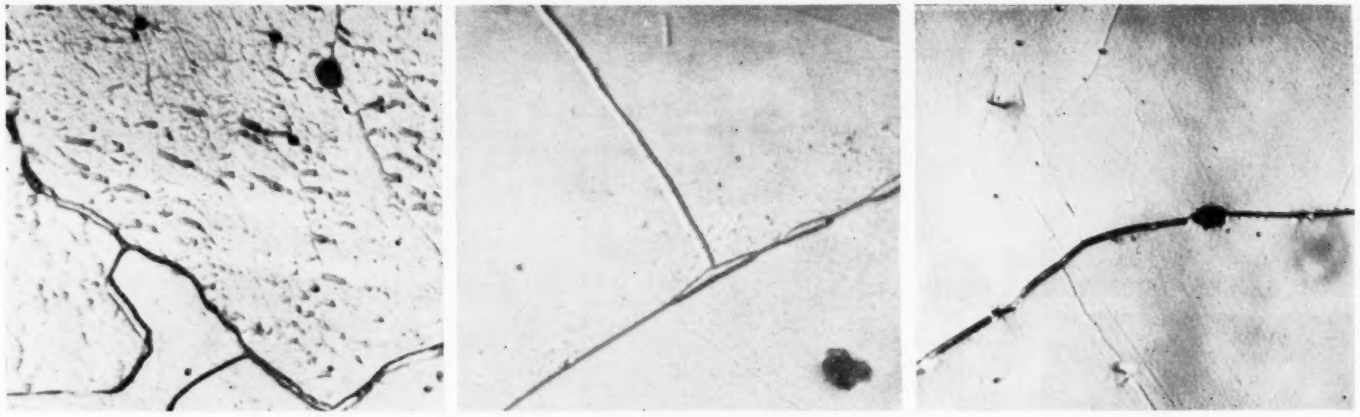

Fig. 2—Ingot iron : (*a*) As received, showing vein markings ; (*b*) after removal of vein markings by heating at 900° C. for 4 hr. and furnace cooling ; (*c*) after quenching from 700° C. Optical photomicrographs × 2000

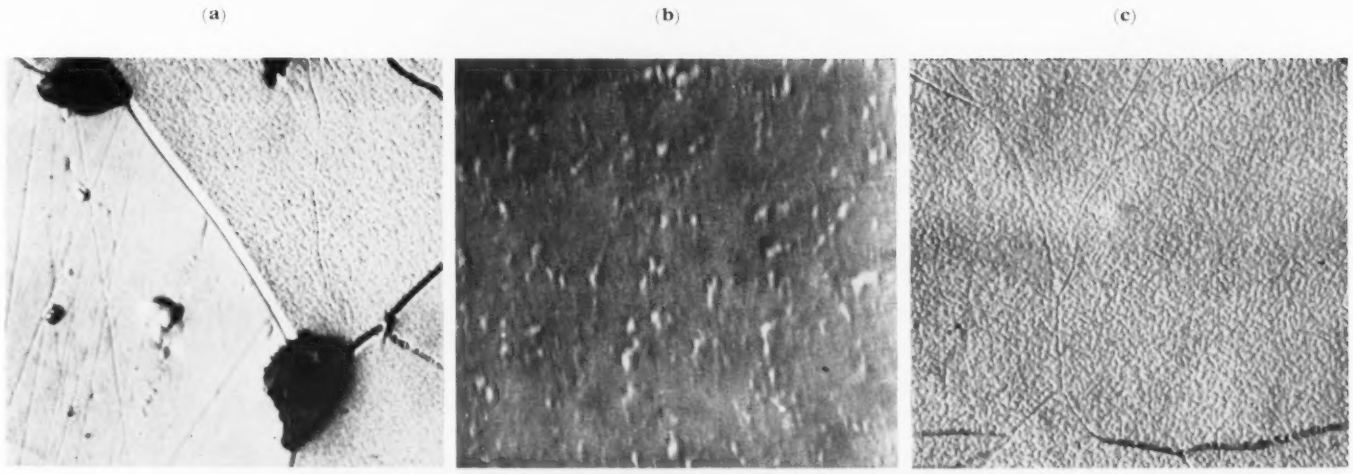

Fig. 3—Ingot iron quenched from 700° C.: (*a*) Aged for 1 hr. at 100° C., showing mottled structure in two adjacent grains (× 500) ; (*b*) electron micrograph of specimen in 3 (*a*), showing discrete precipitates unresolved with the optical microscope (× 21,000); (*c*) aged for 5 hr. at 100° C., showing development of mottled structure (× 1500). 3 (*a*) and (*c*) are optical photomicrographs

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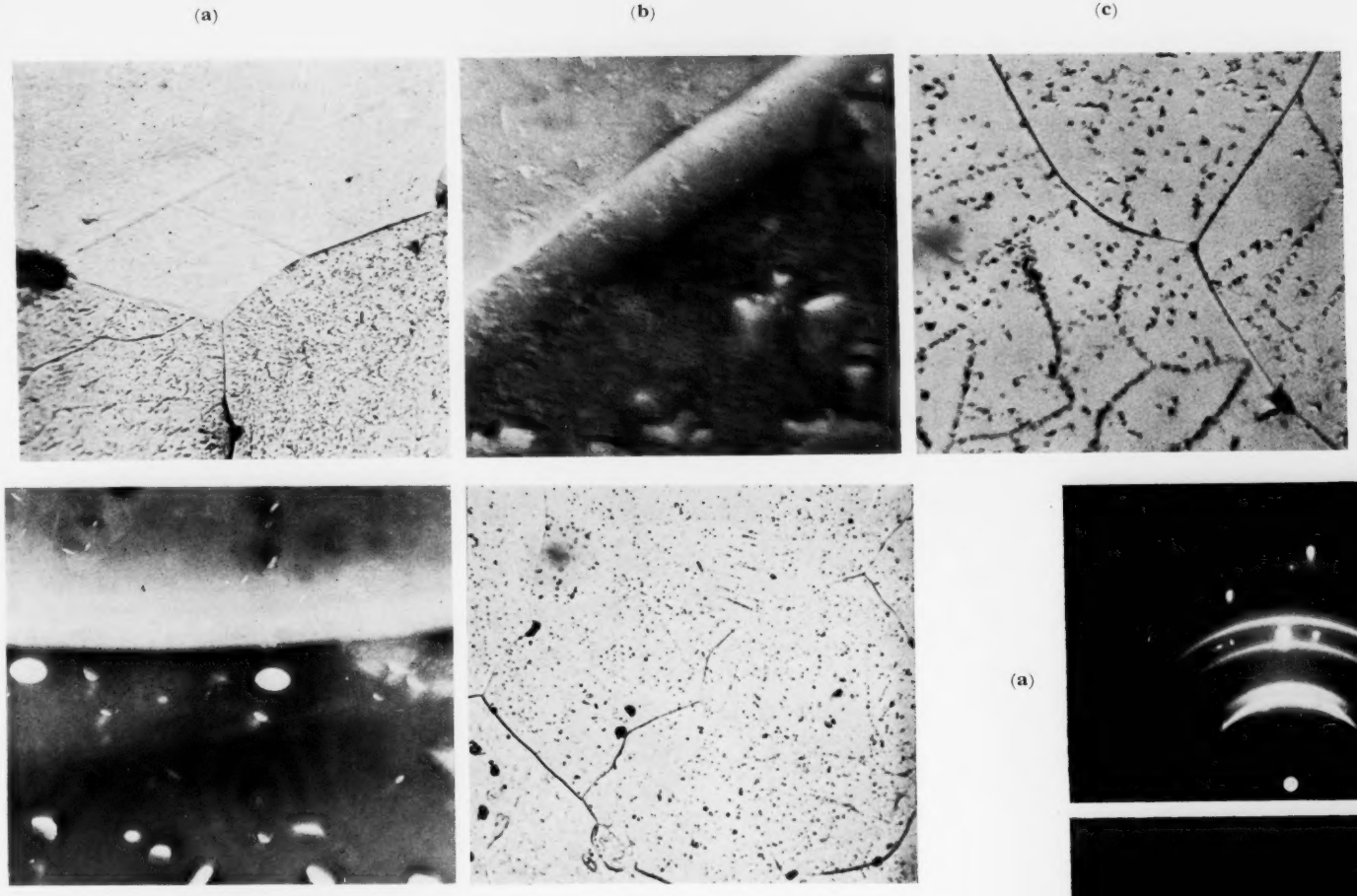

Fig. 4—Ingot iron quenched from 700° C.: (*a*) Aged for 16 hr. at 100° C., showing generalized precipitation within the ferrite grains (× 1000) ; (*b*) electron micrograph of specimen in 4(*a*), showing plate-like shape of precipitates (× 14,000) ; (*c*) aged for 15 hr. at 200° C., showing precipitation at sub-grain boundaries (× 2000) ; (*d*) electron micrograph of specimen in 4(*c*), showing plate-like precipitates (× 6000) ; (*e*) aged for 30 min. at 300° C. (× 500). 4(*a*), (*c*) and (*e*) are optical photomicrographs

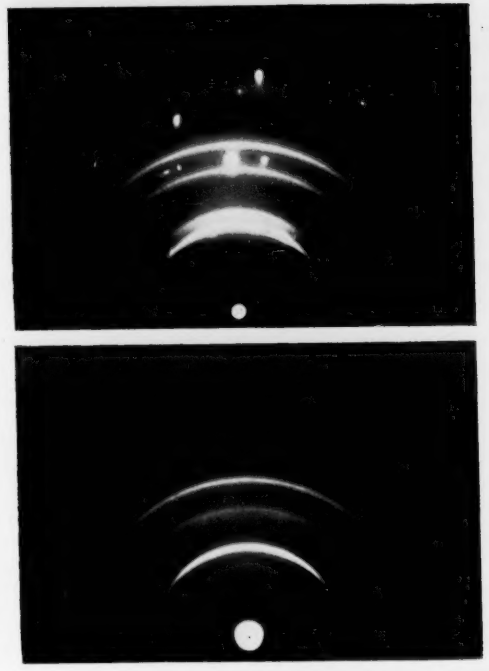

Fig. 5—Electron diffraction pattern from ingot iron after quenching from 700° C.: (*a*) Specimen polished and etched for 40 sec. in 2% nital, showing face-centred cubic pattern of austenite together with weak pattern of ferrite ; (*b*) specimen abraded on 000 emery, showing body-centred cubic pattern of ferrite.

austenite together with weak pattern of ferrite; (*b*) specimen abraded on 000 emery, showing body-centred cubic pattern of ferrite.

Table II

RING RADII AND CORRESPONDING LATTICE SPACINGS FOR IRON QUENCHED FROM 700° C. AND AGED AT 200° C. FOR 15 HR., WITH THOSE OBTAINED BY JACK‖ FOR ε-IRON CARBIDE

Ring Radius, cm.	Intensity	Lattice Spacing, kX	α-Fe*	γ-Fe†	ε-Iron Carbide‖	Intensity	Fe_3O_4
1·10‡	MS	2·385			2·36	M	
1·21‡	MS	2·17			2·16	VW	
1·25	VS	2·10		2·10	2·07	VS	
1·29§	S	2·04	2·05				
1·44	W	1·812		1·815			
1·64‡	MS	1·603			1·60	MS	
1·76	VW	1·493					1·477
1·87§	W	1·405	1·43				
1·93‡	MS	1·360			1·36	W	
2·04	VW	1·287		1·284			
2·13‡	W	1·232			1·23	M	
2·27§	W	1·158	1·16				
2·41	W	1·097		1·094			
2·52	W	1·043		1·048			
2·88§	W	0·904	0·910				
3·09	VW	0·852					
3·20	VW	0·822		0·833			

* A.S.T.M. X-ray index
† Calculated from $a_0 = 3{\cdot}63$ kX.
‡ Intensity of these rings uneven
§ Spots
‖ From K. H. Jack,[21] p. 28, Table I, calculated from $a_0 = 2{\cdot}729$, $c_0 = 4{\cdot}326$ kX.

VS = Very Strong
S = Strong
MS = Medium Strong
M = Moderate
W = Weak
VW = Very Weak

only evidence of α-iron (*see* Fig. 14). In this case the surface asperities were predominantly those of the ferrite. Similarly, after polishing with either magnesia or alumina, there was no evidence of austenite; but on etching in nital or picral, the austenite pattern appeared.

Rapid cooling from the high temperature seemed to be essential for producing the austenite, as a specimen slowly cooled from 700° C. showed no evidence of a face-centred cubic pattern. An attempt was made to transform the austenite, found in a rapidly cooled specimen, to martensite by treatment at a low temperature. Examination of the sample after immersion in liquid air for 30 min. showed no change of the original pattern.

Proof that carbon and possibly nitrogen were necessary for the formation of the austenite was obtained by quenching from 700° C. a sample of very pure iron containing 0·002% of carbon and 0·002% of nitrogen. The diffraction pattern showed no evidence of austenite.

When the austenite rings appeared in the diffraction photograph, they were always complete, but diffuse. This indicates either a strained lattice or a small grain size bearing no relationship in orientation to that of the α-iron crystals around which the austenite is assumed to form. The latter is thought to be the more likely explanation of the diffuseness.

As the ferrite grain size of the specimen was known, it was possible to calculate the total grain-boundary area; then, from the measured thickness of the grain-boundary ridges, the volume-% of austenite could be determined. By assuming the composition of the austenite to lie within the limits 0·8–1·7% of carbon or 1·17–2·33% of nitrogen, it was then possible to calculate the wt.-% of carbon or nitrogen in the iron necessary to give the austenite grain-boundary films. With a film thickness of 1000 Å. and a mean ferrite grain size of 40μ, the amount of carbon or nitrogen in the austenite film when expressed as a percentage of the whole material is 0·006–0·012% of carbon and 0·008–0·016% of nitrogen. The carbon in the iron in excess of that soluble at 700° C. is of this order. It may be that a mixed carbon–nitrogen austenite is formed under equilibrium conditions at temperatures between 600° and 700° C., and this may be retained on quenching. If this were so, then the grain-boundary films would contain much of the nitrogen present in the ingot iron.

Ageing at 100° C.

Two specimens aged at 100° C. were examined. The first was treated for 5 hr., and showed a mottled structure under the microscope; the second had been heated for 16 hr., when the precipitates had grown considerably in size. The diffraction patterns obtained from both of these specimens were indistinguishable from that of the quenched specimen.

Ageing at 200° C.

A specimen treated for 15 hr. was examined, the microstructure being similar to that shown in Fig. 4*c*. The diffraction pattern showed the presence of both α-iron and austenite, but in addition there was a further set of rings. The corresponding lattice spacings agreed very well with the hexagonal structure of ε-iron carbide described by Jack[22] as resulting from the decomposition of martensite by tempering at 120°C.

The observed rings and lattice spacings are shown in Table II, together with the lattice spacings for ε-iron carbide as obtained by Jack.[22]

Ageing at 300° C.

The diffraction pattern obtained after ageing for 30 min. or more no longer showed the α-iron spots

Table III

RING RADII AND CORRESPONDING LATTICE SPACINGS FOR IRON QUENCHED FROM 700° C., AGED AT 300° C. FOR 30 MIN., AND AT 500° C. FOR 17 HR., WITH THOSE OBTAINED BY JACK* FOR CEMENTITE

Aged at 500° C.			Aged at 300° C.			Fe_3C* X-Ray Spacing		
Ring Radius, cm.	Intensity	Spacing, kX., Observed	Ring Radius, cm.	Intensity	Spacing, kX., Observed	Spacing, kX.	Intensity	Plane Index
						3·358	VW	110, 002
						3·018	VW	111
0·93	VVW	2·73	1·015	MS	2·68			
1·00	MW	2·54				2·536	W	020
1·07	MS	2·37	1·15	MW	2·37	2·371	MS	112, 021
						2·248	MW	200
1·14	MS	2·23	1·22	MW	2·235			
1·21	S	2·10				2·207	MW	120
			1·32	VSD	2·06	2·098	MS	121
1·25	S	2·03				2·058	MS	210
			1·36	W	2·00	2·018	M	022 (110α-Fe)
						2·004	VS	103
						1·968	MS	211
1·365	S	1·862	1·46	S	1·865	1·862	M	202, 113
						1·846	MS	122
						1·756	M	212
1·51	VW	1·682	1·63	VW	1·670	1·679	M	220, 004, 023
						1·633	W	221
1·59	MS	1·596	1·71	MS	1·592	1·582	M	130, 123
1·65	MW	1·538				1·539	W	131
						1·506	MW	222, 114
1·79	VVW	1·417				1·409	VW	311
						1·403	W	024
			2·00	VWD	1·361	1·346	VW	230, 204, 223
						1·339	VW	124
1·91	W	1·330				1·326	S	231, 312
1·96	W	1·295	2·11	W	1·290	1·289	VW	320, 133, 105
						1·255	W	232
						1·250	VW	115, 303, 041
2·07	MS	1·226	2·215	MS	1·229	1·221	S	140
						1·212	S	313
						1·202	VW	141
2·17	MS	1·172	2·325	MS	1·172	1·189	MS	224, 025, 042
						1·159	S	233 (211α-Fe)
2·20	W	1·154						
						1·149	MS	134, 125, 142
2·24	MS	1·133	2·40	MS	1·134			
						1·127	W	400, 215
						1·124	S	330
2·29	MS	1·109				1·123	M	006, 323
						1·109	VW	331
			2·46	MS	1·107	1·104	S	240, 043
						1·102	MS	410
						1·095	MW	314
2·40	VW	1·058				1·087	MW	411
						1·066	W	332, 116
			2·59	W	1·052	1·052	MW	234, 225, 242
						1·046	VW	412
						1·026	VW	135, 026, 324
						1·020	VW	421
						1·005	W	333, 206, 305 (220α-Fe)
						1·001	VW	126
2·56	W	0·993	2·74	W	0·993	0·9924	MS	243, 150
						0·9854	S	144, 422, 216
						0·9843	MS	315
2·72	WD	0·934	2·89	WD	0·943			
2·88	WD	0·882	2·97	WD	0·916			
			3·24	WD	0·841			
			3·37	VW	0·809			

* From K. H. Jack,[11] p. 30, Table II

VS = Very strong
S = Strong
MS = Medium strong
M = Moderate
W = Weak
MW = Medium weak
VW = Very weak
VVW = Very very weak
VSD = Very strong diffuse
WD = Weak diffuse
VWD = Very weak diffuse

or austenite rings. The whole pattern agreed reasonably well with that to be expected from the normal iron carbide, orthorhombic Fe_3C. The observed rings are listed in Table III. The corresponding microstructure is similar to that shown in Fig. 4*c*. The X-ray diffraction pattern of cementite found by Jack[22] after tempering martensite at 250° C. showed anomalous intensities of certain lines when compared with the cementite pattern obtained after tempering at higher temperatures. It was thought by Jack[22] that this resulted from the plate-like shape of the cementite particles when first precipitated. When examining the precipitates by electron diffraction, such anomalies should not occur, because of the short wavelength of the electron beam. Calnan and Clewes,[23] when examining by an electron diffraction reflection method the cementite precipitates obtained on tempering martensite for 1 hr. at 250° C., observed only the normal intensities in the diffraction patterns.

Ageing at 500° C.

After ageing for 17 hr., the diffraction pattern showed only the presence of orthorhombic iron carbide. The diffraction data are shown in Table III.

It is thought that the ε-iron carbide pattern obtained after ageing at 200° C. arises solely from the precipitates visible within the grains. The only other possible source would be the decomposition products of the austenite. However, the ε-iron carbide and austenite patterns are visible simultaneously. Moreover, microscopic examination showed that the grain-boundary austenite film was still intact, and that no precipitates were present at the grain boundaries. The absence of rings other than those of normal iron carbide on the specimens aged at temperatures between 300° and 500° C. is very strong evidence that the pattern is derived from the generally distributed precipitates.

DISCUSSION

The precipitation of carbon from a supersaturated solid solution in α-iron is a more complicated process than has been suggested by earlier workers. However, the metallographic changes and the nature of the new phases formed on ageing are very similar to those obtained by tempering high-carbon martensite as outlined by Jack.[22]

There are some differences between the results on ferrites and those on martensite. By X-ray examination, Jack[22] first obtained evidence of ε-iron carbide after tempering for prolonged periods at 120° C. In the present work, no evidence of ε-iron carbide was found by electron diffraction methods until after 15 hr. at 200° C. However, metallographic examination of the ferrite revealed changes even after very short ageing times at 100° C. It is possible that the precipitates observed after treatment for 1 hr. at 100° C. are of ε-iron carbide, but, because of their small size, they are obscured from the electron beam by the high grain-boundary ridges. They are therefore unable to contribute significantly to the diffraction pattern.

In view of the work of Trotter and McLean[24] on the microstructural changes accompanying the decomposition of the martensite, and the structural changes found from X-ray diffraction measurements by Jack,[22] there seems to be little doubt that the supersaturated ferrite decomposes more readily than martensite.

The positions of the carbon atoms in martensite have been discussed by Petch[25] and by Lipson and Parker.[26] They have deduced that the carbon could be situated in the octahedral interstices at the mid-points of the *c* cell edges and at the centre of *C* faces; *i.e.*, at 0, 0, ½ and ½, ½, 0. The carbon atoms can thus distort the body-centred cubic structure of ferrite to a body-centred tetragonal. In this model of the structure there are two carbon atom sites per unit cell; *i.e.*, 100 carbon atom sites for every 100 iron atoms. However, the maximum solubility of carbon in austenite is 1·7% and, therefore, in the resulting martensite there are only 8·2 carbon atoms for every 100 iron atoms. Thus, one in twelve of the possible interstitial sites is filled.

The positions of the carbon atoms in ferrite have been discussed by Snoek[9]; the sites he suggests are the same as those deduced for martensite. If the degree of supersaturation is low, it is probable that the sites at the mid-points of any of the cell edges (*i.e.*, at 0, 0, ½; 0, ½, 0; ½, 0, 0) and at any of the face centres (*i.e.*, at ½, ½, 0; ½, 0, ½; 0, ½, ½) are filled. Thus, the net effect will be a uniform distortion of the structure, so retaining the cubic symmetry of the ferrite.

In this model of the structure, there are six carbon atom sites per unit cell; *i.e.*, 300 carbon atom sites for every 100 iron atoms. The maximum solubility of carbon in ferrite is 0·018%; this corresponds to 0·084 carbon atoms for every 100 iron atoms, and only one in 3600 of the possible interstitial sites is filled. Accordingly, there is negligible interaction between neighbouring carbon atoms. Thus, the ferrite lattice remains cubic as opposed to the tetragonal symmetry of martensite induced by the higher carbon content.

It may be, therefore, that the supersaturated ferrite decomposes more readily than the martensite because the rate of diffusion of carbon in ferrite is greater than in martensite. In the ferrite there is a greater variety of vacant interstitial lattice sites than in the martensite, and this may lead to a lower activation energy for diffusion, so increasing the coefficient of diffusion. This increase may be sufficient to offset the much greater concentration gradients that may be obtained when a martensite is decomposing than when the supersaturated ferrite is decomposing. Although the diffusion coefficient and activation energy for diffusion of carbon in ferrite are known, no similar results are available for the diffusion of carbon in martensite.

The microstructure at the peak of the hardness curve shows some unusual features in regard to the size of the precipitated particles. From the work of Mott and Nabarro,[27] it is possible to calculate that the maximum hardening to be expected from a dispersed carbide phase in a ferrite matrix will occur when the particle separation is about 300 Å. Knowing the amount of carbon available for precipitation and assuming that the composition of the ε-iron carbide is Fe_3C, the calculated size of the spherical carbide to give a mean separation of 300 Å. is about 50 Å. dia.

The particles shown in Fig. 3*b*, which correspond to those found at the peak of the hardness, are 300–500 Å. dia., and their average separation is about 2000 Å. This may mean that the maximum hardness found after ageing at 100° C. is well below the maximum hardness that it is possible to produce in the material by some alternative ageing treatment. A specimen of the iron aged for six months at room temperature showed a hardness only slightly higher than that obtained after ageing for one hour at 100° C.

The presence of precipitates at the sub-grain boundaries is an interesting phenomenon. It is thought that the precipitates form at random positions throughout the ferrite and that preferential growth of those originally present at the sub-grain boundaries then occurs with an increase in the ageing time and temperature. This structure may be a result of (*a*) the lower strain energy generated by growth of the precipitates at regions where the lattice is thought to be slightly disorientated, and (*b*) the increasing rate of diffusion with increasing temperature. Similar arguments apply to the subsequent growth of the precipitates at the grain boundaries, where an even greater degree of disorientation is present than at the sub-grain boundaries. However, complete precipitation may not occur initially at the grain boundaries, although these are the most favourable sites because of the relatively large distances over which diffusion of the carbon would have to take place.

The transition from the hexagonal to the orthorhombic carbide has been discussed by Jack.[22] He assumes that the hexagonal carbide has a composition near Fe_3C, and that, by a nucleation and growth process within the crystal, the hexagonal structure can transform to the orthorhombic by a series of simple atom movements. On this theory, no change in microstructure would be expected during the course of the transition. An alternative method of transformation outlined by Jack[28] would be for the hexagonal carbide to nucleate the orthorhombic carbide, or for cementite to be nucleated within the matrix. Growth could then take place by precipitation from the matrix of cementite on to the nuclei, and the simultaneous solution of the ε-iron carbide. This mechanism would imply that the carbon content of the matrix in pseudo-equilibrium with the ε-iron carbide is greater than the carbon content in pseudo-equilibrium with the cementite. In this case a change in type of microstructure might be expected.

Crangle and Sucksmith,[29] from the results obtained when investigating the decomposition of martensite by magnetic methods, believe that the composition of the first-formed carbide is Fe_2C, and that this changes with increasing temperature to $Fe_{20}C_9$—a carbide having a low order of symmetry—which subsequently changes to the orthorhombic Fe_3C. This series of changes would be expected to result in a change in the microstructure, because a transition from Fe_2C to Fe_3C would involve a 50% increase in volume of the carbide, assuming a constant amount of carbon available for precipitation.

In the present investigation, no evidence of the intermediate carbide $Fe_{20}C_9$ has been detected. It must be admitted, however, that in view of the complexity of the $Fe_{20}C_9$ pattern, it may not be possible to resolve it sufficiently clearly with the electron diffraction reflection technique. The microstructure obtained after 15 hr. at 200° C. was almost identical with that found after 30 min. at 300° C.; yet, in the former, the diffraction pattern showed the hexagonal carbide, and in the latter the orthorhombic Fe_3C. This sequence of changes appears to involve the direct transformation of ε-iron carbide to Fe_3C.

From X-ray diffraction examination, Jack[22] concluded that cementite, when first precipitated, had a plate-like shape; this agrees with the present results.

As pointed out by Jack,[28] the precipitation of carbon from supersaturated solid solution in ferrite follows closely that observed for the precipitation of nitrogen. In the iron–nitrogen system, the sequence of changes is

supersaturated ferrite α (body-centred cubic) $\rightarrow \alpha''$ ($Fe_{16}N_2$)
$\alpha''(Fe_{16}N_2) \rightarrow \gamma'$ (Fe_4N)

In the iron–carbon system the sequence is

supersaturated ferrite α (body-centred cubic) → ε-iron carbide
ε-iron carbide → cementite (Fe_3C).

SUMMARY AND CONCLUSIONS

The quench-age-hardening of iron can result from the precipitation of a carbide from a supersaturated solid solution of carbon in α-iron. When ageing at 100° C., maximum hardness occurs after one hour's treatment. At this stage, precipitates have been detected with the aid of the electron microscope, and these are of size 300–500 Å. dia., but, because of their diffuse outlines, their shape is not precisely known. When the ageing time is increased beyond one hour, there is growth of the precipitates and a corresponding decrease in the hardness of the metal. After 16 hr. at 100° C., the precipitates are plate-like in shape and about 500 Å. thick and 2000–3000 Å. dia.

With an increase in the ageing temperature to 200° C., a series of changes similar to those observed at 100° C. occurs. The maximum increase in the hardness is found after 5 min. and, with further ageing, the plate-like precipitates increase in size and form preferentially at the sub-grain boundaries within the ferrite crystals. By electron diffraction, it now becomes possible to identify the structure of the precipitates as the hexagonal ε-iron carbide. When the ageing temperature is increased to 300° C., a change in the crystal lattice of the precipitates occurs. After 30 min. at this temperature, the diffraction pattern of cementite (orthorhombic Fe_3C) is observed, but there is no change in the microstructure. At still higher temperatures, the cementite particles grow preferentially at the ferrite grain boundaries, with a corresponding decrease in size and number of the precipitates within the grains and at the sub-grain boundaries.

The sequence of the changes that occur on ageing is

supersaturated ferrite → ε-iron carbide
ε-iron carbide → cementite (Fe_3C)

This sequence is very similar to that observed during the decomposition of a carbon martensite, but the supersaturated ferrite decomposes more readily than martensite. It is deduced that this occurs because of the greater variety of lattice sites available for diffusion in the ferrite.

Iron specimens with a total carbon content of 0·026 wt.-%, of which 0·015% is held in supersaturated solid solution by quenching from 700° C., have been found to contain austenite as a grain-boundary film. The composition of the austenite is estimated to be between 0·85–1·7% of carbon or 1·17–2·33% of nitrogen, but it is thought to be a mixed carbon–nitrogen austenite. No mechanism is advanced to account for its presence, but some of the factors responsible for its formation are known.

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Train Arrivals, Handling Costs, and the Holding and Storage of Raw Materials

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SYNOPSIS

The sizes of trains and incidences of arrival are examined to find out how these affect the capacity of reception sidings required to accommodate incoming wagons.

Based on costs of handling materials and stocking on the one hand, and wagon charges on the other, consideration is given to the economic balance between storing material on the ground and holding wagons under load in sidings. The greatest economy is generally obtained by aiming at holding wagons in the works for not longer than the effective free standage period of 1·5 days, depending on costs of equipment available.

A simple formula is suggested that is designed to give adequate siding capacity in relation to terminal user time and irregularity in arrivals.

THE rate of consumption of materials in a steelworks may be regarded as reasonably constant from day to day, in spite of known week-end variations. The quantities of materials arriving daily may, however, be far from constant; the arrivals will take place intermittently, in whole train loads at a time, the train loads themselves being dispersed with variable intervals between them.

These differences between arrival and consumption

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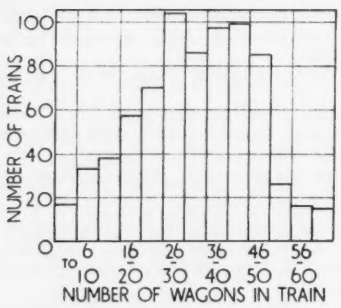

Fig. 1—Number of wagons per train load

rates present two problems to the steelworks:

(i) The works' transport system must convert scattered, intermittent batch arrivals into a steady flow; this may be done by having sidings into which the trains are delivered from the main-line railways, and from which the individual commodities can be removed steadily to other parts of the works. Such sidings may be termed ' reception sidings '

(ii) The works' transport system must also be able to accommodate surplus commodities over periods when arrivals exceed consumption, and bring them forward when arrivals fall short of consumption: *i.e.*, there must be capacity to hold stock. Such stock may be in wagons, for which sidings will be required (termed as ' holding sidings '), or in bunkers, or on the ground in a stockyard. Whether commodities are kept in wagons or stored on the ground depends on the availability of wagons, and the cost balance between unloading and reloading wagons on the one hand, and paying standage on the other.

It is proposed to consider how these irregularities in arrivals and traffic and handling costs affect the amount of sidings needed in a steelworks. Comparison is made with sidings in existing works. It is convenient to consider reception and holding sidings separately, although the distinction is not always well defined. Only the principal commodities are referred to, although the collective importance of other commodities in moderate use must not be overlooked; arrivals other than from main-line railways (*e.g.*, by water or on private lines) are not considered. Only short-term stock requirements are discussed, without reference to such matters as commercial policy having long-term effects.

OBJECTIVES

The objectives of this paper are:

(i) To examine train arrivals and irregularities, and to determine the siding capacities required for wagon reception

(ii) To determine the quantities of inward material that should be held in wagons rather than put to storage, and the siding capacities required for holding wagons

(iii) To compare siding capacities computed on a theoretical basis with actual capacities in a number of works.

RECEPTION SIDINGS

The object of reception sidings is to enable the works to accept trains of wagons as they are delivered by the main-line railways and to pass the wagons to other parts of the works in small consignments at a steady rate. Obviously, the average rate of removal of wagons from the sidings should equal the average rate of arrival. The size of the reception sidings necessary to convert the intermittent arrivals into a steady flow of removals will depend on the size of the train load in relation to the average removal rate, and also on the regularity of intervals between successive trains.

For example, if consumption in a works is at a steady rate of 17 wagon loads per hr., and one train of 17 wagons is delivered every hour, the reception-sidings capacity would only need to be 17 wagons. In fact, trains of up to at least 50 wagons must be expected, but if a train of 50 wagons is delivered every 3 hr., the reception sidings need only be large enough to accommodate 50 wagons, since each train could be dispersed to holding sidings before the next train is due. British Railways, however, naturally prefer to deliver trains as they arrive in the locality; and if they are to be accepted without delay, the capacity of the reception sidings will have to be further increased.

An analysis of the actual train arrivals at a works during $2\frac{1}{2}$ months in January–March, 1949, is given below. The number of trains that arrived was 745; they are analysed according to size of train and intervals between trains, and the effect of these two factors on reception siding capacity is considered.

Size of Trains

Figure 1 shows the number of wagons per train load that arrived. The average number of wagons per train was about 33, but the size of train varied throughout the range up to 80 wagons, and the mean size is not clearly defined. The size of train is not constant, and calculations cannot be based on any expectation of trains of a particular size.

Intervals between Trains

Figure 2 shows the relative frequency of different intervals between successive trains. The broken line in this figure shows the distribution of intervals that would be expected if the train arrivals were, in general, statistically random, *i.e.*, if no control were exercised to schedule arrivals, and trains arrived at the works

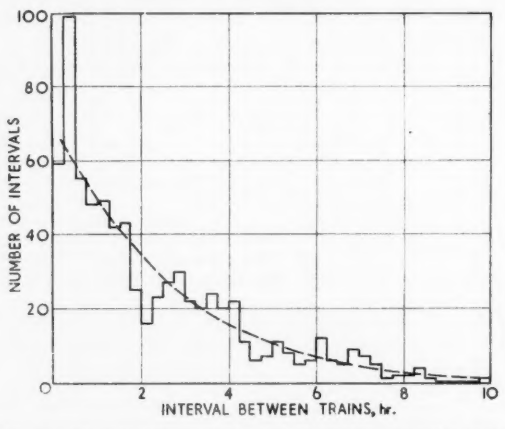

Fig. 2—Distribution of time intervals between train arrivals. Histogram shows time actually found for 745 trains; broken line shows theoretical distribution if interval sizes are random

quite independently of one another. There is reasonable agreement between the observed values and this theoretical distribution, except for a markedly large number of intervals of between 16–30 min. There is no obvious reason why this interval should be so popular; the probable explanation is that there is a tendency to have an abnormal number of intervals up to $\frac{1}{2}$ hr., but that during the first $\frac{1}{4}$ hr. there is an opposing effect due to the need for a minimum interval between trains. It was impossible to confirm this suggestion since, although the train arrival times are recorded to the nearest 5 min., examination of the arrival times shows a marked predilection for the quarter and half hours. Ten of the intervals, not shown in the histogram in Fig. 2, were over 10 hr.; these all occurred on Sundays, when it appears to be the custom to deliver a few trains early in the morning, and then no more until late at night or early on Monday morning.

Figure 3 shows the distribution of the actual arrival times according to the hours of the day. It reveals a definite tendency for trains to arrive at particular times of day.

These two figures show that little attempt is made to arrange a regular flow of trains, which would be simplest for the reception sidings. Indeed, there is a suggestion that the bunching of trains is worse than would be expected if arrivals were completely at random, owing to the tendency for arrivals to be concentrated at particular times of the day.

Reception Siding Capacity

The combined effect of the variable numbers of wagons per train load and of the variable intervals between trains can be seen in Fig. 4. It is constructed on the following assumption:

(i) The sidings are empty at the beginning
(ii) Entries into the sidings are those actually shown by works records
(iii) Wagons are removed from the sidings at a steady rate of 20 wagons per hr., whenever there are wagons in the sidings awaiting removal.

It will be seen that at one time over 250 wagons are in the sidings. With an approximately random distribution of train arrivals, not only the reception siding capacity, but also the facilities for removing wagons from the reception sidings have to be greater

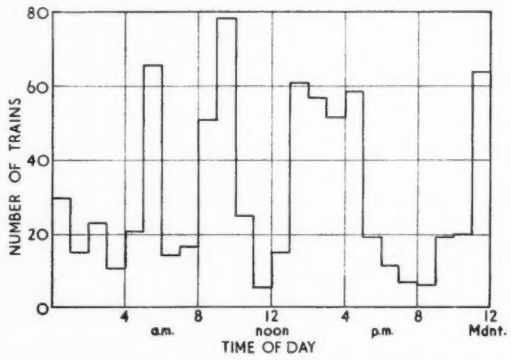

Fig. 3—Distribution of arrival times of 745 trains by time of day

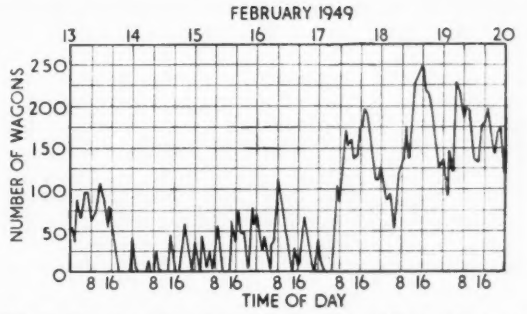

Fig. 4—Number of wagons in reception sidings, derived from known arrivals and assumed rate of removal of 20 wagons per hr.

than would be required for regular arrivals. In the present instance, a removal capacity of 20 wagons per hr. has been indicated against the average of $16\frac{1}{2}$ wagons passing through in an hour, on the reasonable assumption that traffic facilities should be able to handle 20% above the normal flow. The maximum found in this example then suggests that reception sidings should cater for average arrivals during about 16 hr. or 2 shifts, which is borne out by practical experience. Siding capacity and removal capacity are complementary; if the wagons were removed faster than the rate of 20 wagons per hr. assumed, the peak number in the sidings would fall below 250. Thus, for any given arrival distribution, the steelworks can adjust sidings capacity and removal capacity in such a way as to minimize cost.

HOLDING SIDINGS

When the wagons are removed from the reception sidings, one of three things can happen:

(i) The wagons can be taken straight to the consuming department and emptied, if the contents are required for immediate use
(ii) The wagons can be taken to some place where the material can be unloaded immediately into storage, and reloaded when required
(iii) The wagons may be held full in the holding sidings and emptied later, when the contents are required.

Holding sidings or material storage are alternative

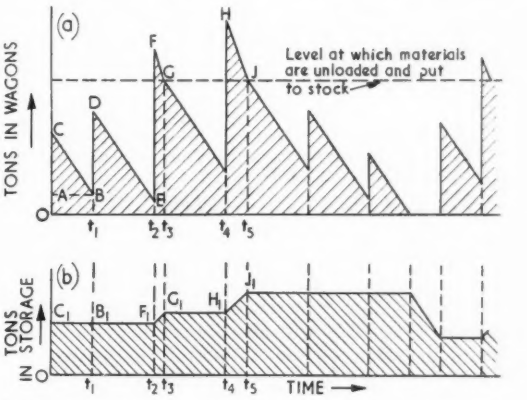

Fig. 5—Material quantity record: (*a*) In wagons, (*b*) in storage

ways of balancing irregular arrivals with fairly regular consumption. This can be shown, as in Fig. 5, by a graph giving material quantities in wagons (*a*) or in storage (*b*); tonnages are plotted against time. A horizontal portion of the graph corresponds to a constant tonnage of materials over a period, and an inclined portion to a rate of storage addition or withdrawal.

At time t_0, there are C tons of materials in the sidings and C_1 tons in the stockyard. Since the blast-furnaces, for instance, consume at an approximately steady rate, materials will be drawn out of the sidings at a steady rate, and this is shown in Fig. 5*a* by line CB. Meanwhile, the level in storage remains constant, as no materials have been drawn from stock. At time t_1, a fresh arrival of materials is delivered to the works, and the tonnage in the sidings is now D. Materials are then once more drawn away from the sidings down to point E, when an influx brings the materials in the sidings up to point F. This is above the limit at which it is considered that materials must be unloaded to storage, bringing the stock in wagons down to point G. The quantity of materials in storage will then go up from F_1 to G_1, and so on.

From this it can be seen that it is impossible to determine the amount of siding capacity required without considering the appropriate balance between putting to storage and holding in sidings. This may, of course, often depend on special local restrictions, *e.g.*, there may not be land available to build more sidings; in the main, however, this balance will depend on economic factors, which must first be briefly considered; in practice, however, the decision to store material is ultimately a matter of judgment assisted by experience.

Costs

The items of cost that enter into a comparison between keeping stock in wagons and putting it to the ground are:

A. Stock Held in Wagons until Required	B. Stock Stored on the Ground
1. Cost of moving wagon from reception to holding sidings	1. Cost of moving wagon from reception sidings to material storage
2. Charges for wagons during movements to holding sidings	2. Charges for use of wagons during movement to material storage
3. Charges for wagons held in sidings	3. Cost of unloading wagons to material storage
4. Cost of holding sidings	4. Cost of material storage space
5. —	5. Cost of reloading from material storage
6. Cost of moving wagon to consuming department	6. Cost of moving reloaded wagon to consuming department
7. Charges for wagon during movement to consuming department.	7. Charges for reloaded wagon during movement to consuming department.

Items 1 and 6 may be taken to be the same for both methods. Item *B*4 will also be small per ton, and is ignored. The essential items for comparison are, therefore, charges for wagons and sidings cost on the one side, and unloading and reloading costs on the other.

Some figures of these costs, obtained from the records of a number of works, and supplemented in some cases by direct observation and time studies of cranes operating, are given in Appendix I. The main costs may be summarized as follows:

(i) Charges for use of incoming wagons (items *A*2, *A*3, *A*7, and *B*2) will be at basic standage rate of 2*s.* 9*d.* per wagon per day,* subject to a free standage period of 1·5 days.† Charges for item *B*7 will be for internal hire, or for the upkeep of works wagons, depending on the system of ownership. For internal hire the charge is 2*s.* per day; the capital cost and depreciation on a new wagon owned by the steelworks might be about 2*s.* 9*d.* per day; for an old wagon they would be less. Thus, charges for items *A*2 and *B*2 can be regarded as the same. The difference between items *A*7 and *B*7 will be small, and can be ignored. The cost balance to be determined depends, therefore, on the comparison between items *A*3 and *A*4 on the one side, and items *B*3 and *B*5 on the other

(ii) Costs of unloading and reloading wagons vary widely, depending on the nature of the commodity and on the type of equipment being used. With conventional equipment of small crane and grab, a total in-and-out cost of about 2*s.* 6*d.* per ton (32*s.* for a 13-ton wagon) appears to be common, and this figure will be used

(iii) The cost of sidings is mainly depreciation and interest on the original capital cost of building them; this will depend on the amount of civil-engineering work necessary, which will vary widely, according to the nature of the site. A figure of 6*d.* per wagon length per day will be assumed for siding cost.

Charges for use of wagons depend on the number of days for which the wagons are retained, and the cost of sidings may also be expressed on a daily basis. Unloading and reloading costs, on the other hand, are ' once-for-all costs,' and do not depend on the number of days the stock is in the stockyard. The problem is to equate these two types of cost.

Irregular Arrivals

The need for holding sidings only arises because arrivals do not exactly conform to consumption. There are, however, many ways in which lack of conformity may arise and, as with reception sidings, the actual arrival distribution is a vital factor affecting the best siding capacity. Just as arrivals at the reception sidings are random in time, as shown in Fig. 2, so the arrival of commodities from day to day in the holding sidings may also be expected to be irregular, showing great variability about some mean. In such circumstances, there is no certainty about the arrivals to be expected on any particular day. It may be, however, that, taking a number of days together, the distributions of arrivals do conform to some common statistical pattern. The distribution of daily arrivals of individual commodities will be considered to see whether they do follow some common pattern, and how the optimum siding capacity is affected by actual distributions found.

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* H. H. Mardon and M. D. J. Brisby, *J. Iron Steel Inst.*, 1949, vol. 163, pp. 434–437; and Demurrage Regulations—Standage Schemes: Memorandum of agreements between British Railways and the British Iron and Steel Federation, Appendixes *A*, *B*, *C*, *D*, and *E*.

† The free standage period is 1·33 days, but since no count of wagons is made on Sundays, the free standage, which is calculated on a weekly basis, is effectively $1{\cdot}33 \times 7/6 \cong 1{\cdot}5$ days. The 2*s.* 9*d.* rate is that applying to integrated iron and steel works.

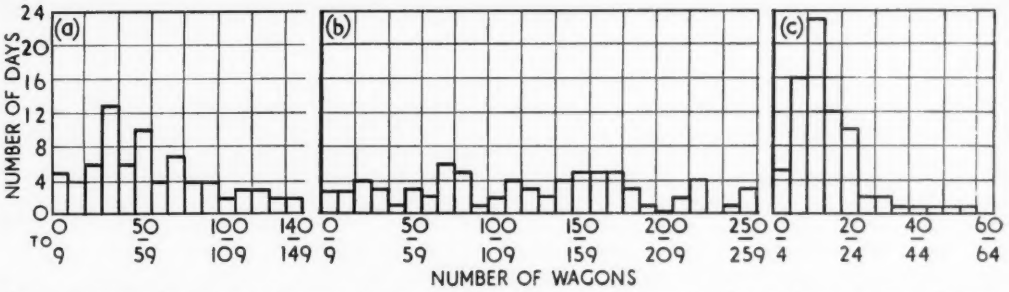

Fig. 6—Distribution of arrivals according to number of wagons per day: (*a*) Ore wagons; (*b*) coal wagons; (*c*) scrap wagons

Figure 6 shows the frequency distribution of daily arrivals of wagons for the three principal commodities (ore, coal, and scrap) at the same works, and for the same period (75 days) as the earlier analysis of arrivals at the reception sidings. These three distributions do not in any way conform to a common pattern. That for coal is particularly scattered; at first sight, it appears that on any day there may be an equal chance of anything up to 250 coal wagons being delivered; in fact, this is not so, since there is a marked weekly cycle, as can be seen from the figures of average daily arrivals given in Table I.

Since the arrivals of these different commodities do not conform to any common pattern, it does not seem profitable to attempt to apply a common analysis to them. As an initial approach, therefore, it was decided to work out the effect of various siding capacities in particular cases.

Example I—To compute the size of scrap sidings for which costs are minimum.

The following rules have been applied to the actual scrap arrivals given in Fig. 6*c*:

> At the beginning, the sidings are assumed to be half-full; consumption is assumed to be constant daily equal to the mean arrivals over the sample period of 75 days. If the day's arrivals exceed consumption, the excess wagons are added to those in the sidings, so long as there is room for them, and when the sidings are full, any further wagons are discharged to storage. Similarly, if arrivals are less than consumption, wagons in the siding are used first, and, if consumption is still not satisfied, more wagon loads are then picked up from storage.

The actual figures for the first few days of the scrap arrivals are shown in detail in Table II, which is worked out for a siding capacity of 20 wagons and mean daily arrivals of 15·7 wagons (1176/75).

The table was continued in this form for the whole of the 75 days available, and the whole period is shown in Fig. 7, in the style suggested in Fig. 5. The sum of the second column gives the total number of wagon days standing during the period (it is similar to the 6 a.m. daily count actually made in the works); the sum of the third column gives the total arrivals, and the sum of the sixth the total number of wagons discharged to storage. The same calculation has been made for other siding capacities, and the numbers of wagons in sidings and discharged to storage are summarized as follows:

Total No. of Days	Total Arrivals	Siding Capacity	Total Wagon Days Standing	Total Wagons Discharged to Storage
75	1176	12	253	132
75	1176	16	344	111
75	1176	20	444	100
75	1176	24	530	93
75	1176	27	610	88
75	1176	31	705	82
75	1176	35	800	75
75	1176	39	900	69

The average number of wagons standing per day is just under one-third of the siding capacity.

From these figures, the costs of handling these 1176 wagons can be derived directly. The total costs are made up of:

(i) Cost of sidings
(ii) Cost of wagon usage, and
(iii) Cost of unloading and reloading.

Charging the sidings at 6*d*. per wagon length per day, wagon usage at 2*s*. 9*d*. per wagon per day, and unloading and reloading at 32*s*. per wagon, the total

Table I

ARRIVALS OF COAL WAGONS ON DAYS OF THE WEEK

Day of Week	No. of Days	Total Wagons	Av. Wagons per day
Sunday	**11**	**993**	**90**
Monday	**11**	**541**	**49**
Tuesday	**11**	**962**	**87**
Wednesday	**11**	**1311**	**119**
Thursday	**10**	**1672**	**167**
Friday	**10**	**1722**	**172**
Saturday	**11**	**1788**	**163**

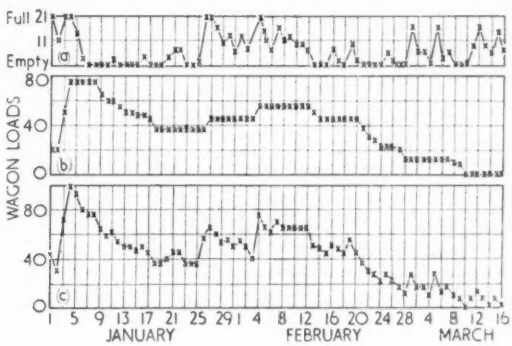

Fig. 7—Daily stock position for scrap, January–March 1949: (*a*) Stock in sidings; (*b*) ground stock; (*c*) total stock

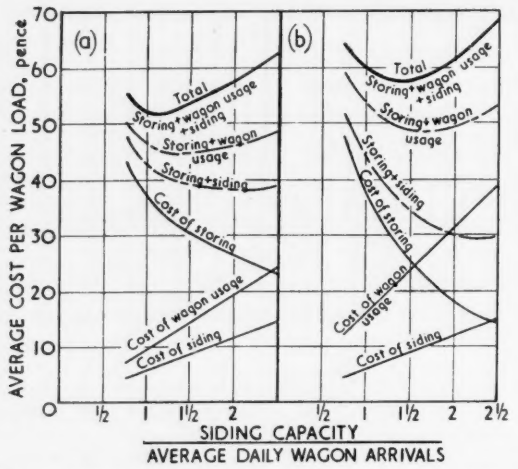

Fig. 8—Effect of siding capacity on costs: (*a*) Scrap wagons; (*b*) coal wagons

costs for sidings of 20 wagon lengths would be as follows:

Cost of siding for 75 days	= 75 × 20 × 6*d*.	= £37½
Cost of wagon usage	= 444 × 2*s*. 9*d*.	= £61
Cost of unloading and reloading	= 100 × 32*s*.	= £160
		£258½

(*See* col. 4, Table III).

Similarly, costs for sidings of other wagon lengths have been computed, and are shown in Table III.

Table III shows that for the given wagon arrivals, sidings of about 18 wagon lengths incur minimum costs. Provided that sidings are operated according to the rules given, the greatest economy is obtained with a fairly rapid turn-round of wagons and moderate siding capacity.

Dividing the costs in Table III by the total number of wagons handled (1176) gives an average cost per wagon load. These are shown graphically in Fig. 8*a*, where the size of siding is expressed as the ratio of the siding capacity to the mean daily arrivals; this ratio can be generally used, since it enables direct comparisons to be made between different sidings, irrespective of the number of wagons with which they have to deal.

Over the range considered, the cost of wagon usage increases approximately linearly as the siding capacity increases, as do the siding costs, which are linear by definition. The unloading and reloading costs, on the other hand, fall as siding capacity increases. Generally speaking, there will be a particular siding capacity at which the sum of the costs will be a minimum. The line of best fit for the four points of the unloading and reloading cost curve has been calculated, and also its slope for different values of siding capacity. Hence, the point at which the total costs are a minimum can be determined. This is shown in Fig. 8*a* for scrap.

Comparing the unloading costs in this way with siding cost alone, wagon-usage cost alone, and the sum of siding and wagon-usage cost, gives the following values for the ratio of siding capacity to average daily arrivals at which the costs are minimal:

Cost to be Minimized	Value of Siding Capacity Ratio
Unloading and reloading cost + siding cost	2·2 (*see* Fig. 8*a*)
Unloading and reloading cost + wagon-usage cost	1·5 ,,
Unloading and reloading cost + siding cost + wagon-usage cost	1·1 ,,

Example II—The 8989 coal wagons that arrived during this same sample period have been treated in exactly the same way, and their average costs per wagon are set out in Fig. 8*b*. In this case, the values of the ratio of siding capacity to average daily arrivals at which the sum of the unloading and other costs is a minimum are:

Cost to be Minimized	Value of Siding Capacity Ratio
Unloading and reloading cost + siding cost	2·4 (*see* Fig. 8*b*)
Unloading and reloading cost + wagon-usage cost	1·6 ,,
Unloading and reloading cost + siding cost + wagon-usage cost	1·4 ,,

On comparing the costs for the scrap wagons and for the coal wagons, marked differences in the effect of increased siding capacity on their unloading and wagon-usage costs can be seen; these differences can be ascribed to differences in the arrival distributions. In spite of them, the optimum siding capacity (in relation to mean daily arrivals) to minimize combined unloading and wagon-usage costs is of the same order in each case.

The cost of wagon usage is most likely to be composed of standage charges to British Railways. The charge is 2*s*. 9*d*. per wagon per day, based on the average for all wagons in the works and calculated

Table II

DAILY DETAILS OF SCRAP ARRIVALS

Day	Wagons in Siding at Start	Arrivals	Total Wagons to be Disposed (Col. 2 + 3 − 15·7)	Wagons in Siding at End	Wagons put to Stock	Wagons Picked up from Stock
Jan. 1	11	49	44·3	20 (full)	24·3	
,, 2	20	4	8·3	8·3		
,, 3	8·3	58	50·6	20 (full)	30·6	
,, 4	20	40	44·3	20 (full)	24·3	
,, 5	20	10	14·3	14·3		
,, 6	14·3	3	1·6	1·6		
,, 7	1·6	12	− 2·1	0		2·1
,, 8	0	16	0·3	0·3		
,, 9	0·3	3	−12·4	0		12·4
,, 10	0	10	− 5·7	0		5·7
	etc.		etc.		etc.	

weekly, but an effective free standage period of 1·5 days per wagon is allowed, during which no charges are made. The cost curves shown in Fig. 8 are based on an assumption that wagon charges of 2*s.* 9*d.* per day are paid from the beginning. In practice, an allowance must be made for the free standage period; *i.e.*, in general, the standage charge would be nil until the costs in the figures rose above 4*s.* 1*d.* per wagon (*i.e.*, 2*s.* 9*d.* × 1·5), after which they would be 4*s.* 1*d.* less than the cost shown.

There are three different situations to be considered when determining the best procedure for minimizing costs:

(i) *In planning siding capacity for a new works as a whole*—In this case, full allowance should be made for the free standage period, and it is therefore appropriate to consider first the effect of siding capacity on storing and siding costs only. The optimum siding-capacity factor to minimize unloading and siding costs for the scrap wagons is 2·2, and for the coal wagons 2·4. In both cases, the wagon-usage cost curve is well below 4*s.* 1*d.* per wagon with this size of siding, so that the siding cost alone is sufficient to limit the capacity, and (provided that the rules for operating sidings apply) it would not be profitable to install sidings so large that standage charges would arise

(ii) *In planning new sidings for a particular commodity*—It may be that it is known that for certain commodities wagons will inevitably be held up; *e.g.*, the cost of unloading bricks is so great, when allowance is made for damage, that it is advisable to hold bricks in their wagons until they are wanted. How far is it profitable to reduce the delays to wagons for some other commodity, *e.g.*, ore, to offset the long delays to the brick wagons? In this case, the ore wagons may properly be considered as incurring standage charges from the start, and the appropriate objective is to minimize the sum of unloading, wagon usage, and siding costs; this is achieved, in the two instances considered, with a siding capacity factor of 1·1–1·4. If this figure is applied to the ore wagons in question, it would not be profitable to reduce the ore siding capacity below about 1·2 days' supply (and so put up ore unloading costs), however great the standage charges falling on the brick wagons might be

(iii) *In considering the use of existing sidings*—As the sidings are existing, and their cost will be relatively small for maintenance only, it is appropriate to consider only the minimization of material storage and wagon-usage costs.

Summing up the findings of this section, it must be emphasized that the calculations relate to particular scrap and coal arrivals, and can only be regarded as examples of the type of information that can be derived; no consideration has been given to any factors other than economic ones. A number of finer points also require consideration, although they are difficult to assess quantitatively. For example, it may not be necessary to reserve particular sidings solely for the use of one commodity; if so, a rather lower cost for sidings would be justified. On the other hand, a somewhat lower cost for unloading equipment may be appropriate in some circumstances, since the costs given refer to the costs of operating the equipment with normal annual usage. But a stockyard is of little use unless there is sufficient equipment and labour available to supply materials from stock quickly enough to keep the works going in an emergency. At other times, such equipment may have to be kept standing idle unless it is used for unloading wagons, in which case the cost of using it for such unloading may be less than appears on a normal accounting basis. The analysis seems to indicate that the greatest economy may be obtained by aiming at retaining wagons in the works on the average for rather less than the effective free-standage period of 1·5 days.

Regular Arrivals

Although it is more usual for arrivals to be irregular, there are circumstances when commodities arrive at regular intervals in consignments of several days' consumption at times which are known in advance.

For example, there might be a scheduled train that arrives every Monday bringing enough of a particular commodity for 7 days' consumption. Should the complete train load of wagons be put into sidings on arrival and the wagons emptied only as required during the week (thereby incurring standage charges), or should some of the wagons be discharged immediately into the stockyard, and the commodity picked up from there again when wanted later in the week (thereby reducing standage charges, but incurring unloading and reloading costs)? And if the latter, how many should be so discharged?

Before this problem can be answered, one further assumption must be made; this concerns the amount of the siding capacity initially used by the consignment that should be charged for. For example, let it be decided that, of a consignment of 50 wagons, 25 should

Table III

COSTS WITH VARIOUS SIZES OF SIDINGS

1176 scrap wagons arriving over 75 days

Size of Siding, Wagon Lengths	12	16	20	24	27	31	35	39
Ratio $\frac{\text{Siding Capacity}}{\text{Av. Daily Wagons}}$	¾	1	1¼	1½	1¾	2	2¼	2½
Cost of siding for 75 days, £	22	30	37	45	51	58	66	73
Cost of wagon usage, £	35	47	61	73	84	97	110	124
Cost of unloading and reloading, £	212	178	160	148	140	130	120	111
Total cost, £	269	255	258	266	275	285	296	308

be kept in holding sidings to be used first as required and the rest put to ground to be used later. Then siding capacity for 25 wagons would be required at first; this would, however, gradually empty during the first half of the week, and would stand empty for the second half of the week, and could be used for other commodities if required. Should the charge be made for 25 wagons' capacity of sidings for the whole week, or for half the week? It is considered most realistic to charge for the sidings for half the week, *i.e.*, for the period during which any wagons of the consignment are standing in them, it being assumed that they are used for some other purpose for the rest of the time.

On this assumption, with wagon and material storage costs as before, it is shown in Appendix II that it is economic to provide sidings to hold complete consignments for direct consumption, if they arrive at known regular intervals for up to eight days' supply. Such arrival conditions may justify the development of cheap storage methods, however, and the economic holding time is balanced with alternative storage unloading and reloading costs below.

Table IV shows how the optimum siding capacity varies according to the unloading and reloading cost, with the other conditions remaining unchanged; it also shows the total savings per consignment by holding various numbers of wagons loaded in sidings as compared with unloading them all immediately to stock. For example, suppose consumption of a commodity is 10 wagons per day; then if, on the arrival of each consignment, two days' consumption (20 wagons) are put in sidings and the balance of the wagons are emptied first into the stockyard, there would be a saving of $15{\cdot}5 \times 10 = 155s.$ per consignment, compared with the cost of unloading the entire consignment to stock immediately on its arrival, when unloading and reloading costs are 13*s.* per wagon. This is irrespective of the size of the consignment, provided that it exceeds two days' consumption.

Table IV

UNLOADING COSTS IN RELATION TO SIDING CAPACITIES

Saving by keeping stock in wagons compared with immediate unloading of all wagons, shillings per consignment

Siding Capacity		Cost of Unloading and Reloading 13-ton Wagons*			
		13*s.*	19½*s.*	26*s.*	32*s.*
No. of days stock kept in wagons	1	9·7 W	16·2 W	22·8 W	28 W
	2	15·5 W	28·5 W	41·5 W	52 W
	3	17·4 W	36·8 W	56·4 W	72 W
	4	15·4 W	41·0 W	67·1 W	89 W
	5	8·8 W	41·3 W	73·9 W	101 W
	6	− 1·2 W†	37·6 W	76·7 W	109 W
	7	−15·5 W†	30·0 W	75·5 W	113 W
	8		18·3 W	70·3 W	113 W
Optimum capacity of sidings, days		3	4½	6	7½

* W = consumption, wagon loads per day
† Negative sign indicates a loss instead of a saving

TERMINAL USER TIME AND SIDING CAPACITY

Design Formula for Holding Sidings

It has already been shown that costs may often be least when the size and organization of the holding sidings are so arranged that the wagons are, on the average, turned in rather less than the effective free standage period of 1·5 days. This, however, referred only to the holding sidings; allowance must be made for standage charges accumulating from the moment the wagons enter the works while they are being moved up to the sidings. Furthermore, it was tacitly assumed that when it becomes necessary to empty wagons to stock, this can be done instantaneously; this is clearly impossible, and some further delay will occur there. Inadequacy of the unloading facilities to deal promptly with wagons is the ultimate cause of congestion, which may result in high standage charges. On the other hand, the payment of standage charges makes costs rise rapidly and it appears unlikely that, except in special cases, it will be profitable to organize the traffic system deliberately so that standage charges are paid. The most economic arrangement will therefore be to aim at keeping wagons on the average for the free standage period, *i.e.*, to work to a terminal user time of about 1·5 days. What does this imply in terms of total siding capacity (excluding reception sidings)?

Let n be the average number of raw material wagons entering the works per day. Then the average number of loaded wagons in the works at any one time will be nT, where T is the terminal user time. Thus, for a terminal user time of 1·5 days:

$$\text{Av. number of loaded wagons in the works} = 1{\cdot}5\ n$$

In the analysis of the scrap and coal wagons, it was found that with the coal wagons, whose arrival distribution was approximately symmetrical (*see* Fig. 6*b*), the sidings would be on the average about half full, so long as the procedure outlined for loading and unloading was followed. This would be in accordance with general expectation, since with a symmetrical arrival distribution the sidings would, on the average, be as likely to be full as empty.

With the scrap wagons, however, which had a markedly asymmetrical arrival distribution (the peak of the curve in Fig. 6*c* is well to the left), the sidings were only, on the average, about one-third full. This is also to be expected, since, with an arrival distribution of this shape, there will be more occasions when the sidings are empty than when they are full.

With an arrival distribution asymmetrical in the opposite direction (*i.e.*, with a peak to the right and a long tail to the left), the sidings would, on the average, be more than half full. A distribution markedly asymmetrical in that direction would, however, be unlikely; nevertheless, it is apparent that on the average the fullness of the sidings would vary at least over the range from half full down to about one-third full, depending on the distribution of arrivals.

If the average number of wagons in the works at any one time is to be 1·5 n, and the sidings are on the average one-third to about half full, then the

Table V—WORKS EXISTING SIDING CAPACITIES

	Allocation of Sidings		Works A	Works B (Old)	Works B (New)	Works C	Works D	Works E	Works F
			Wagon Lengths (20 ft.)						
Reception and Departmental Sidings	Oven coal	In		100	720		302	449	305
		Out		80	360				
	Coke	In	40	40	80			612	
		Out	40	10	75				
	Ore	In	125	20	30		94†	422†	300
		Out		10	75				
	Scrap	In	100	75	170				
		Out		80	150				
	Oxides, limestone, slag, etc.	In		40	60			201	
		Out		10	75				
	Finished steel	Out	105				270	201	
	Other commodities	In					82		
		Out							
	Miscellaneous and cripples	In						433	
		Out							
	Empties	In					172	301	
		Out					80	712	
	Docks	In				250*			
		Out				30*			
	Total capacity of reception sidings	In	265	275	1060	372*	1150	2418	605
		Out	145	190	735	125*	350	913	
		In + Out	410	465	1795	497*	1500	3331	605
Internal Sidings	Coke ovens	Total		70	170		80	1159	715
	Blast-Furnaces General		44	50	25		80	956	500
	Coke		43					407‡	55
	Ore		262				150	1096**	665
	Limestone		31						1055
	Other		402	20	150				
	Empties							507	
		Total	782	70	175		230	2966	2275
	Melting shops General		42	200	180	102	40	528	515
	Scrap		392			125	90		475
	Oxides							180	
	Limestone						30	153	
	Other		179				20		480
	Empties							211	
		Total	613	200	180	227	180	1072	1470
	Rolling mills General		155			50		449	200
	Steel		133	50	50	349	60	755	260
	Empties							248	
		Total	288	50	50	399	60	1452	460
	Miscellaneous (goods, coal, cripples, and maintenance)			95	70	55		871	
	Empties							443	
		Total		95	70	55		1314	
	Total allocated		1683	485	645	681	550	11294	4920
	Total not allocated		730	100	180	75			630
Total Mileage	Sidings		9·1	10·5	15·0	3·0	7·8	42·78	29·3
	Special lines (Brit. Rlys., tips, etc.)		1·7			2·0*		4·24	
	Running lines		5·2	9·0	16·3	5·0	32·2††	52·18	3·7
	Total railway tracks in works		16·0	19·5	31·3	8·0	40·0	99·20	33·0

* Sidings or running lines owned by British Railways
† Excluding ore from local mines
‡ Bought coke
** Ore from Northants and local mines
†† Includes lines to private mines, etc.

siding capacity C required must be between the limits of $3{\cdot}0\ n$ and $4{\cdot}5\ n$; *i.e.*,

$$3{\cdot}0\ n < C < 4{\cdot}5\ n \quad \ldots\ldots(1)$$

To this must be added a 'float' factor to allow space for shunting and movement of wagons of, say, 10%. A further addition must be made for outgoing wagons after they have been unloaded, since standage charges cease from the moment the wagon is discharged. Empty wagons will naturally be removed from the works as quickly as possible to reduce congestion, although they may stand about the works for several hours. The average may be taken as a quarter of a day.

With these two additions, therefore, the holding capacity required for incoming loaded wagons, excluding reception sidings, is likely to fall within the range

$$3{\cdot}5\ n < C < 5{\cdot}25\ n \quad \ldots\ldots(2)$$

Thus, if a works has 3000 inward loaded wagons weekly, the siding capacity suitable for a terminal user time of 1·5 would be

$$3{\cdot}5 \times \frac{3000}{7} < C < 5{\cdot}25 \times \frac{3000}{7}$$

$$1500 < C < 2250 \text{ wagons}$$

Taking the average wagon length to be 22 ft., the siding length required for holding inward raw materials would then on the average be expected to be between $6\frac{1}{4}$ and $9\frac{1}{2}$ miles.

Existing Sidings

The sidings of six integrated iron and steel works have been examined to compare their capacities; these are listed in Table V. In Table VI they are compared with computed capacities derived from formula (2), and from the throughput tonnages given in Tables VII and VIII.

Because of the diversity in the allocation and usage of sidings in different works, the figures in Table V sometimes show little consistency, and caution should be exercised when comparing siding capacities. Where it has not been possible to enter the siding capacity under the headings of particular materials or departments, these have been entered under 'general,' 'other,' or 'miscellaneous.'

In Table VI the throughput is given in tons and wagons per hour. Formula (2) gives siding capacity in terms of multiples of days' consumption. For the blast-furnace departments, wagons have been assumed to hold 17 tons, a mean between the 13-ton common user wagon and the 20-ton ore hopper.

Works B and C together form an integrated unit. There are few sidings in the blast-furnace department, owing to the direct discharge of sea-borne foreign ore. Works B has expanded considerably, and for comparison both the old and new figures are given in Table V.

From Table VI, comparing the actual siding capacities with the computed, there is fair agreement, except at works A and F, in both of which the existing sidings are very large. Works A has a very old layout with a large number of short sidings. Owing to the situation of Works F, the train arrivals are infrequent

Table VI

COMPUTED AND EXISTING SIDING CAPACITIES

The appropriate lower (3·5) and higher limits (5·25) have been used in computing the siding capacities, in accordance with the particular pattern of arrivals of coal, ore, and scrap found in Fig. 6

Works	Department	Average Throughput		Computed Siding Capacities $3{\cdot}5\ n < C < 5{\cdot}25\ n$*		Existing Siding Capacities
		Tons/hr.	Wagons/hr.	$\frac{C}{n} = 3{\cdot}5$	$\frac{C}{n} = 5{\cdot}25$	
Works *A*	Blast-furnaces†	39·3	3·0		380	782
	Melting shops	31·6	2·4		300	613
Works *B* (old) and *C*	Coke ovens	57·0	4·4	370		300
	Blast-furnaces‡	35·5	2·1		260	150
	Melting shops	41·2	3·2		400	427
Works *D*	Coke ovens	51·5	4·0	340		382
	Blast-furnaces	88·0	5·2		650	230§
	Melting shops	28·4	2·2		280	180
Works *E*	Coke oven	180·0	14·0	1180		1159
	Blast-furnaces	315·0	18·5		2340	2459‖
	Melting shops	57·9	4·5		570	861
Works *F*	Coke ovens	43·0	3·3	280		715
	Blast-furnaces	68·0	4·0		500	2275
	Melting shops	39·6	3·1		390	1470

* n = Av. number of raw material wagons entering works per day
† Throughput tonnages include coke
‡ Home ore only included
§ Works have private mines and quick turn-round of private wagons
‖ Includes home ore sidings

Table VII

THROUGHPUT OF MATERIALS IN BLAST-FURNACES AND OPEN-HEARTH FURNACES, 1948

Works	Infeed to Blast-Furnaces																		Output of Blast-Furnaces			
	Quantity, tons × 10³										Rate, tons/hr.								Quantity, tons × 10³		Rate, tons/hr.	
	Iron Ore										Iron Ore											
	Home										Home											
	Raw	Calcined	Imported	Sinter	Scrap	Limestone	Cinder	Slag	Scale	Total Burden	Coke*	Raw	Calcined	Imported	Total	Sinter	Scrap	Limestone	Cinder	Slag	Scale	Total Burden	Coke	Pig Iron	Slag†	Pig Iron	Slag
A	128·6	…	32·3	6·6	22·5	7·8	10·2	8·5	9·1	225·6	97·9	14·7	…	3·7	18·4	0·8	2·6	0·9	1·2	1·0	1·0	25·9	11·2	92·0	78·0	10·5	9·0
B	177·8	…	533·6	19·3	0·8	79·6	…	32·5	…	843·6	328·4	20·4	…	61·1	81·5	2·2	0·1	9·1	…	3·7	…	96·6	37·6	348·7	174·0	39·9	19·9
D	474·3	…	93·2	164·8	28·9	…	2·4	…	4·0	767·6	298·2	54·3	…	10·7	65·0	18·9	3·3	…	0·3	…	0·5	88·0	34·1	242·3	230·0	27·7	26·4
E	1997·9	…	3·1	707·4	8·3	…	11·8	5·1	19·9	2753·5	1056·1	228·7	…	0·4	229·1	81·0	1·0	…	1·4	0·6	2·3	315·4	120·9	807·4	1030·0	92·4	118·0
F	241·8	62·6	193·7	…	17·0	41·6	5·8	29·2	1·7	593·4	279·1	27·7	7·2	22·2	57·1	…	2·0	4·8	0·7	3·3	0·2	68·1	32·0	238·3	153·0	27·3	17·6
H	471·8	389·9	1588·6	…	58·9	516·1	10·8	27·6	23·2	3086·9	1306·5	54·0	44·6	181·8	280·4	…	6·7	59·1	1·2	3·2	2·7	353·3	149·6	1227·9	1070·0	140·6	123·0

Works	Total Furnace Capacity	Infeed to Open-Hearth Furnaces																					Output of Open-Hearth Furnaces				
		Quantity, tons × 10³											Rate, tons/hr.										Quantity, tons × 10³	Rate, tons/hr.		Slag (approx.)
		Molten Metal	Pig Iron	Scrap			Imported Ore	Scale	Other Oxides	Finishings	Fettling Materials	Total Charge	Molten Metal	Pig Iron	Total Scrap	Imported Ore	Total	Scale	Other Oxides	Finishings	Fluxes	Fettling Materials	Total Charge	Ingots	Metal for Casting	Total	Ingots	Metal for Casting	Total	Rate, tons/hr.
				Cast Iron	Turnings	Other than Turnings																							
A	620	87·4	18·8	6·6	2·5	196·6	4·6	1·2	…	5·4	29·3	11·2	363·6	10·00	2·16	23·54	0·52	0·14	…	0·62	3·35	1·28	41·61	296·7	…	296·7	33·96	…	33·96	66·9	7·65
B, C	981	188·9	20·8	3·3	32·4	224·3	7·2	8·3	1·5	6·3	43·4	12·3	548·7	21·62	2·38	29·75	0·83	0·94	0·17	0·72	4·96	1·41	62·78	416·9	0·5	417·4	47·72	0·06	47·78	131·6	15·07
D	840	212·3	26·4	…	0·1	91·7	55·5	9·1	…	4·6	44·7	16·4	460·8	24·30	3·03	10·50	6·35	1·05	…	0·52	5·12	1·88	52·75	315·4	…	315·4	36·10	…	36·10	145·5	16·65
E	2550	610·8	0·9	4·4	1·3	235·5	68·3	58·1	1·3	7·6	100·4	28·2	1116·8	69·92	0·10	27·61	7·81	6·66	0·15	0·87	11·50	3·23	127·85	828·0	0·9	828·9	94·78	0·10	94·88	288·8	33·06
F	700	193·3	5·5	2·1	23·9	205·8	17·2	18·6	…	3·6	51·2	17·8	539·0	22·13	0·63	26·54	1·97	2·13	…	0·41	5·87	2·04	61·72	370·3	1·3	371·6	42·38	0·15	42·53	168·9	19·33
H	3800	996·4	49·0	30·9	7·3	471·4	211·2	35·5	0·1	19·6	178·2	73·6	2073·2	114·06	5·61	58·33	24·18	4·06	0·01	2·25	20·40	8·43	237·33	1557·6	0·5	1558·1	178·29	0·06	178·35	515·7	59·63

* Coke tonnage actually charged (handled tonnage 7–10% greater)
† Slag tonnage calculated from appropriate ratio of cwt.° of slag per ton of iron

Table VIII

CONSUMPTION OF STEEL IN ROLLING MILLS, 1948

Figures are in thousands of tons

Works	Ingot Consumption*	Plates (Heavy and Medium)	Rails, Sleepers, etc.	Sections, Bars, etc.	Light Rerolled Strip	Hot-Rolled Strip	Wire Rods	Total Hot-Rolled	Cold-Rolled Strip	Wire	Coated and Uncoated Sheets	Total Steel Production
A	293·7	...	...	19·4	135·6	...	...	...	...	...	...	155·0
B, C	393·2	100·7	115·5		...	...	...	...	...	...	...	216·2
D	301·3	271·9	semi-finished, dispatched to other works for finishing									
E	808·5	331·0	164·7		60·0	...	...	...	...	...	...	555·7
F	381·0	...	19·5		54·4	13·7	222·8	290·9	3·7	...	...	310·4
H	1523·8	246·6	52·3		142·2	...	26·3	168·5	...	2·6	68·8	1016·2

* These figures differ from the ingot production in Table II by stock changing, etc.

and materials are held in wagons for 3–4 days. The traffic resembles the regular rather than the irregular arrivals on which the formula has been based.

CONCLUSIONS

(1) The sizes of trains arriving at an integrated iron and steel works are not constant, and calculations cannot be based on the expectation of trains of a particular size. The number of wagons per train is found to vary from below 5 up to 80, with an average of about 33.

(2) The distribution of intervals between trains appears to be such as might be expected if no control were exercised to schedule arrivals, and trains arrived at the works quite independently of one another. There is, however, a definite tendency for trains to arrive at particular times of day: between 5–6 a.m., between 8–10 a.m.; between 1–5 p.m., and at about midnight.

(3) The combined effect of the variable numbers of wagons per train load and the variable intervals between trains may cause the number of wagons in the reception sidings to vary from 0 up to at least 250 in a particular case studied, where the average arrivals were 396 per day. This suggests that if congestion is to be avoided, the reception sidings should be large enough to accommodate the average arrivals during two shifts, a figure borne out by practical experience.

(4) The distribution of arrivals of the three principal commodities—ore, coal, and scrap—do not in any way conform to a common pattern. Coal arrivals appear to be particularly scattered, with anything up to 200 wagons being delivered on one day, but closer examination shows that there is a distinct weekly cycle, with heavy arrivals towards the end of the week.

(5) Holding sidings and material storage are needed because arrivals do not conform closely to consumption. To determine the most economical siding capacity to install, consideration must be given to the cost of putting to storage and holding in sidings. The main costs affecting this balance are:

(i) Standage at a rate of 2*s*. 9*d*. per wagon day, payable after a free period of effectively 1·5 days

(ii) Costs of unloading and reloading wagons, which vary from 1*s*. to 2*s*. 6*d*. per ton (13*s*. to 32*s*. for a 13-ton wagon)

(iii) Cost of sidings—about 6*d*. per wagon length per day.

(6) In assessing the size of sidings required, their capacity is best measured as a multiple of an average day's consumption of wagon loads. The greatest economy will nearly always be obtained with siding capacity such that wagons are retained in the works on the average for rather less than the effective free standage period of 1·5 days. This figure has been obtained from the costs quoted above with storing charged at 32*s*. per wagon, and is in no way influenced by the national policy for quick turn-round of wagons.

(7) To maintain an average turn-round time of 1·5 days, the holding sidings for main inward commodities need to hold between 3½ and 5 times the average daily consumption. Sidings of this capacity should provide an adequate margin for irregular arrivals.

(8) In certain cases, which appear to be rare, arrivals may follow a well-defined pattern, with known long intervals between regular consignments. In such circumstances, it can be shown that, on purely economic grounds, it may pay to have holding siding capacity exceeding eight days if the storage cost is taken as 32*s*. per wagon. But the standage scheme is operated on the understanding that wagons are turned round as fast as possible, and if the storage cost were reduced to 13*s*. per wagon, the optimum siding capacity would be only three days' supply. Where these circumstances exist, therefore, it would appear preferable to concentrate on improved and cheaper storage facilities rather than on laying out large areas of sidings.

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APPENDIX I

Traffic Operating Costs

STANDAGE CHARGES

These are taken at 2*s*. 9*d*. per wagon per weekday, subject to a free standage period of 1·5 days per wagon. Higher charges are made for certain larger wagons, but these are ignored in this report. Standage charges are calculated on the average delay to all wagons in the works over a period of a week. Any particular wagon, by being unloaded in less than the free period of 1·5 days, may, therefore, in effect be balancing standage on other wagons that have been retained over 1·5 days.

PRIVATE WAGONS

If the cost of a soundly built general-service wagon is taken as £400, and if interest and depreciation are charged at 12½% *per annum*, the cost will be about 2*s*. per day.

SIDING COSTS

The construction of new sidings is a heavy capital expense, which will vary widely according to the nature of the area where the sidings are built. A cost of £50–75 per wagon length may be taken as normal where a certain amount of civil engineering work is necessary to prepare the formation. If 15% *per annum* on the latter figure is allowed to cover interest, depreciation, and maintenance, the cost of sidings will be 8*d*. per wagon length per day.

The cost of laying sidings with second-grade material, including turnouts and on reasonably good ground, is about £38 per wagon length, *i.e.*, a cost of 4*d*. per wagon length per day.

The cost of laying plain track without turnouts, with second-grade material, and on reasonably good ground, is about £28 per wagon length.

Track maintenance costs are about £800 per mile per year, *i.e.*, about 60*s*. per wagon length or 9*s*. per yard. This works out at about 2*d*. per day, so that the total charge for sidings per day would be 6*d*. per wagon length for second-grade sidings with turnouts.

LOCOMOTIVE COSTS

The cost of locomotives varies considerably from works to works. A figure of 25–30*s*. per loco-hour may be taken as a fair average.

RUNNING COSTS

Total locomotive, wagon, and track costs range from 2*d*. per ton mile, for the heaviest traffic with straightforward terminal arrangements, to 10*s*. per ton mile for light irregular traffic.

APPENDIX II

Balance between Stock in Wagons and Ground Stock

If train loads of a commodity arrive at scheduled times with a known long interval between arrivals, the following simplified analysis may be appropriate in assessing the best balance between stock kept in wagons and stock put to ground:

Suppose that a commodity that is consumed at a steady rate of y wagons per day arrives at intervals in batches of D days' supply (*i.e.*, Dy wagons) at a time. This might apply to foreign ore arriving from an unloading port.

Let it be profitable to put x days' supply of wagons in sidings, the remainder being unloaded into stock, assuming that the siding capacity of xy wagons is fully occupied by and is therefore charged to this consignment, so long as any of the wagons are still in it. Then:

Average consumption rate	y wagons/day
Wagons put in sidings	xy wagons
Wagons put in stock	$Dy - xy$ wagons
Siding cost	0·5*s*. per wagon length per day
Standage	2·75*s*. per wagon per day
Cost of unloading and reloading	32·0*s*. per wagon.

Of the total of xy wagons put into the sidings, y removed the first day may be taken to incur 1 day's standage each, y removed the second day will incur two days' standage each, etc. The total number of wagon-days standage incurred will therefore be

$$y + 2y + 3y + - - - + xy = y.\tfrac{1}{2}x(x + 1)$$

Therefore the total standage cost for the wagons put to sidings will be $2{\cdot}75\, y.\frac{1}{2}x(x + 1)$. The sidings cost will be $0{\cdot}5x^2y$. Unloading and loading cost will be $32y(D - x)$.

Total cost is:

$$\begin{aligned} &2{\cdot}75y.\tfrac{1}{2}x(x + 1) + 0{\cdot}5x^2y + 32y(D - x) \\ &\quad = y/24\ (45x^2 - 735x + 768D) \end{aligned}$$

For this to be a minimum:

$$\begin{aligned} 90x - 735 &= 0 \\ x &= 8 \end{aligned}$$

From this it appears that, in the conditions postulated, it does not pay to put to stock any wagon whose contents will be consumed within eight days of arrival; up to that time, it is more profitable to keep the wagons loaded in sidings and pay standage. The conditions, notably the assumptions as to sidings occupation, and the cost of unloading and reloading the commodity at the stockyard, may be varied and, if so, a different number of days will apply.

Development of Active Mixer Practice at Appleby-Frodingham

By A. Jackson, A.Met., F.I.M.

SYNOPSIS

This paper describes experiments on the treatment of iron between the blast-furnaces and the mixer, and the development of mixer practice, at the Appleby-Frodingham Steel Company.

The first part discusses open-top and semi-closed ladles for metal transfer; trials of insulated ladles; loss of sulphur by flotation from the iron during transit, and the effect thereon of additions of manganese-bearing materials to the ladle at the blast-furnaces; treatment of molten iron by ladle reaction with iron oxide, limestone, and fluorspar; the removal of silicon, manganese, and carbon by oxygen lancing; and the use of soda ash for desulphurization.

The second part considers mixer construction, design, and refractories; fuels and fuel consumption; the effect of iron quality on mixer capacity; the method of feeding, using local ironstone or limestone and scale; the mixer process developed in a steel furnace; the effect of rate of feeding on sulphur removal in the mixer, and the effects of the high- and low-silicon iron produced on steel-furnace production rates; the loss of sulphur in transit and mixer operation, with the effects of mixer slag volumes; the general results obtained, and a method of estimating operational efficiency; the effect of direct and mixer iron on steel-furnace production; and the oxygen lancing of mixers.

Introduction

ACTIVE mixer practice, and other positive methods of modifying the composition of blast-furnace iron before charging into the steel furnaces, are likely to find wider application in this country, owing to the reduced availability of scrap. The need for pre-treatment in a specific practice increases with the proportion of iron to be used; some of the added costs may be recovered in reduced costs of subsequent processes, increased production, or the ability to improve steel quality.

The Appleby-Frodingham steel furnaces have traditionally used over 75% of molten iron in their tilting furnaces during the last half-century. Following the construction of the third tilting furnace, they brought into operation their first active mixer about 35 years ago. As the degree of activity increased, the original blast-furnace gas-heated mixer gave place to what resembles in all respects a large modern steel-making furnace.

It is considered that this record of the history and development of active mixer practice will be of especial use to the iron and steel industry at the present time. The results are not final, and would not all satisfy the statistician or the pure scientist. Steel-making works to close cost limits, and any variation in the process will show a sharp increase in costs, so that, for the practical operator, a few trials of a new procedure are often enough to show it to be uneconomical or impracticable, and on this basis it is discontinued. Fundamental research would require the statistically correct number of trials to be performed, so that the precise loss per ton could be recorded, but, in works practice, this is only done when the initial trial shows sufficiently promising results.

Much of the information and many of the results given are based on such rough practical trials, and the processes were, consequently, discarded. It is not suggested, however, that in other conditions they would not be considered satisfactory. The rough trials that have proved satisfactory have been incorporated into standard practice, so that these records may suggest that everything tried has been unsatisfactory.

Some of the records or trials go back many years, but the results are still considered to be representative.

Changes in the molten iron begin as soon as it leaves the blast-furnace, and the paper considers all such variations, both natural and induced by treatment, up to the time when the refined metal leaves the mixer.

REFINING OF IRON BEFORE MIXING

TRANSFER OF MOLTEN IRON TO STEELWORKS

Open and Semi-Closed Ladles

Iron was originally transferred at Appleby-Frodingham from blast-furnaces to steel plant in 30-ton open-top ladles, and because of limited crane lifting capacity at Frodingham Mixer, this method persisted until the plant was closed down in 1947.

At Appleby-Frodingham melting shop, 70-ton cylindrical transfer ladles were introduced, before 1930, for handling the iron from the large blast-furnaces. Later, when alterations had been made to rail access, the smaller furnaces could also use this type of ladle.

Molten blast-furnace metal can be kept in these ladles for many hours, if necessary, and will remain fully fluid without appreciable skull loss. They are normally emptied into the mixers as quickly as

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possible to avoid heat loss, which is low compared with that suffered by the 30-ton open-top type.

The following table records the more important features of the two ladle types:

	Open Top (30-ton)	Semi-Closed Top (70-ton)
Iron skull loss (3 years' average), %	2·15	0·35
Ladle life, casts	54	230
Ladle life, tons transferred	1,500	14,500
No. of bricks per lining	600	1,650
Cost per ton (bricks, labour and steelwork), 1944, pence	10·5	5·4

The saving in cost due to reduction in skull loss is greater than the difference in ladle-lining costs, and, if all these figures are considered, the total saving due to semi-closed ladles (on skull relining) was, at that time, 1*s.* 9*d.* per ton. Increased iron costs have further widened this differential.

The major disadvantages are:

(i) Inability to treat the iron in the ladle by soda-ash, scale, or any material that produces important quantities of slag

(ii) Carry-over of blast-furnace slag from cast to cast, with bad effects on subsequent iron analysis

(iii) Possible dangers of serious skulling, although Appleby-Frodingham transferred several million tons of iron for more than 20 years before a top plate had to be removed to extract a large skull.

Blast-Furnace Slag in Transfer Ladles

When slag or 'shoddy' from the blast-furnace is allowed to flow into the iron ladle, it will normally solidify on the surface of an open-top ladle, preventing it from being poured into the mixer. In a semi-closed ladle, however, most of the slag will remain liquid, and will pass into the mixer with the molten iron; any that solidifies will adhere to the ladle lining and be partially remelted later. If the slag is high in sulphur, it will contaminate subsequent casts of better-quality iron. Only a careful watch at both iron and steel works will prevent large quantities of slag from entering the mixer, thus materially reducing the degree of desulphurization possible.

Careful experiments were made to estimate the slag content of blast-furnace metal by pouring into an open-top ladle and skimming; some slag was always present. With poor-quality iron, which showed little slag in the blast-furnace runner, 1·5% (after allowing for ladle erosion) had separated from the shoddy during transit to, and while standing in, the melting shop. This slag may contain 0·7–2% of sulphur, and the 0·3 cwt./ton of iron charged has a great effect on the normal mixer slag. It cannot be removed from the iron ladle in the melting shop, except by first transferring to an open-top ladle, which is expensive and cumbersome.

Every effort must be made to separate slag and iron at the blast-furnaces. The slag is easily visible in open-top ladles, but in semi-closed ladles, only the mixer man can see the slag passing in with the iron; he is generally watching the stream as a whole, and may easily miss it. Failure to complain to the blast-furnaces may make them less vigilant during filling, so that it is sometimes possible for an active mixer to receive over 100 tons of sulphury blast-furnace slag per week, which has a bad effect on mixer practice; it is bought as iron, and ultimately reduces yield from the steel furnaces.

Insulation

Reducing heat loss of iron in transit by insulation was tried many years ago, and the results are summarized below:

(i) The normal lining for the semi-closed ladle consists of two courses of firebrick. For the trials, it was backed by a 3-in. layer of insulation between brickwork and casing. The firebrick courses are termed 'working' and 'safety,' the former alone being normally replaced

(ii) Hard insulation was soon crushed to powder by the continual expansion and contraction of the firebrick lining, and often trickled through the ¾-in. holes drilled in the casing to allow steam to escape when drying new ladles

(iii) The lining life was reduced from 220–250 to 113 and 121 charges, and the safety lining was so permeated with metal that it had to be replaced after each trial

(iv) Soft asbestos-type insulation, 2 in. thick, was better in some respects, but ladle lives were still low (140 and 148 charges)

(v) Ladle capacity in each trial was reduced by about 10 tons (about 14%). This, with reduced life, would have needed important additions to the ladle fleet as compensation. The losses due to skull are normally so low that insulation gives no further reduction

(vi) Full-scale mixer trials made later showed no visible advantages to the steel furnaces attributable to hotter incoming metal; the difficulties of making a a test of this kind are, however, so great that the results are not reliable. Theoretically, it would seem reasonable to expect some advantage from increased iron temperature, *i.e.*, the mixer might be able to deal with more feed, but tests on metal temperature out of the mixer showed the effects of silicon on open-hearth output to be great, compared with those of temperature

(vii) These results confirmed in detail a previous trial, and insulation has not, therefore, been used since.

DESULPHURIZATION BY FLOTATION OF MANGANESE SULPHIDE

In 1948/49, a large number of analyses showed important reductions of the sulphur content of iron during transfer in semi-closed ladles from blast-furnaces to mixers. The figures showed most reduction from the furnaces furthest from the steel plant, thus indicating the possibility of a time effect.

The work of C. H. Herty and J. M. Gaines on manganese–sulphur equilibria, published in 1926 and 1927, was well known, but, early in 1949, it was decided to try to evaluate the changes taking place under the conditions at Appleby-Frodingham.

A series of ladles was carefully observed, using the normal technique of sampling into open moulds. Samples were also taken, using the bomb technique, from various depths below the metal surface, and immersion temperatures were observed simultaneously. Difficulties arose during the preliminary experiments, owing to the sticky slag sometimes found in the ladles, but these were overcome, and a satisfactory technique was developed.

Fourteen ladles were sampled, some quickly after tapping, at various depths, and others at intervals while the metal was standing for up to 8 hr. Thus the effects of time on the rate of reaction could be noted; the concentration of sulphur at various levels was also measured, as it was anticipated that flotation would show a maximum near the metal surface. Slag or scum samples were taken at appropriate times.

Table I

COMPARISON OF SELECTED SAMPLES

Furnace Sample		Time Standing,	Temperature when Emptied, ° C.	Bomb Samples		Trough Runner Samples	
S, %	Mn, %	hr. min.		S, %	Mn, %	S, %	Mn, %
0·045	1·10	2 18	1285	0·077	1·04	0·068	1·02
0·060	1·72	4 12	1275	0·051	1·80	0·043	1·74
0·110	1·08	3 20	1280	0·088	1·13	0·071	1·10
0·204	1·12	3 02	1260	0·153	0·62	0·124	0·56

Summary of Results

In tests of samples from the blast-furnace runner and pig-casting machine troughs cooled in air, the change in sulphur content is based on the tendency to equilibrium shown by the formula:

% of Mn × % of residual S = 0·07 (at about 1300° C.)

The extent of the change in sulphur content is related to the time of standing, experiments showing that, under favourable circumstances, 50% of the sulphur is removed by standing for 6 hr.

On the evidence available, bomb-sampling methods (which cool out of contact with air) apparently have a constant of 0·09. In eight tests, the constants averaged 0·088 and 0·067 for samples from the same ladle, taken by the bomb method and from the pig-casting machine trough respectively.

These figures show that a given iron, when machine-cast into pigs, could show a sulphur content of 0·07%; if charged to the mixer, it would contain 0·09%.

The results tended to confirm work by other authors, which showed the tendency of the constant to fall with falling temperature, *i.e.*, to increase the tendency for sulphur removal to take place.

When the sulphur content of the iron is below the manganese–sulphur equilibrium figure, reversion normally takes place, as the ladles always contain some residual slag after the first two or three casts. This means that low-sulphur blast-furnace iron should be hurried to the mixer, but that high-sulphur metal can stand with advantage, if it contains the necessary manganese.

Slag samples from the ladles showed changes that followed a reasonably regular pattern:

(i) The silica content increases, probably from attack on the lining, to give a SiO_2/CaO ratio of 1·3–1·4
(ii) The MnO content of the slag increases from 1·5%, normal for blast-furnace slag, to about 6%
(iii) The FeO content rises to between 2% and 5%
(iv) Sulphur falls from about 2%, normal in blast-furnace slag, to 0·5–0·7%. This loss is apparently mainly the result of oxidation. This sulphur content is still high, however, and the slag should be prevented from entering the mixer if possible.

Table I gives four selected samples, as illustration only. In studying these, the difficulties of obtaining a representative blast-furnace sample must be considered.

General Practice

A series of open-pot samples was taken from the iron ladles when they arrived at the mixer and compared with normal blast-furnace samples, so as to compare results without reference to time or temperature of metal, slag content of ladle, or other possible variables. This was expected to give an average of the changes taking place under normal conditions. The results were as follows:

Range of Mn. %	No. of Tests	Sulphur at Blast Furnace, Av. %	Sulphur at Mixer, Av. %	(Mn) × (S) = K at Mixer
0·8–1·0	18	0·085	0·078	0·072
1·0–1·2	31	0·078	0·068	0·075
1·2–1·4	25	0·075	0·058	0·075

The average silicon content was 1·11% at the blast-furnaces and 1·07% at the mixer, and the phosphorus content was 1·66%. The sulphur averaged 0·079% at the blast-furnaces, and 0·067% on arrival at the mixer.

When these ladles were charged, 103 samples were taken from the mixer: the average analysis was 0·35% of Si, 0·064% of S, 1·29% of P, and 0·58% of Mn.

These tests show that most of the sulphur elimination between the blast-furnace sample and the iron leaving the mixer was in the transfer ladle, before entering the mixer. With silicon as high as 1·1%, mixer feeding would be heavy, and, under these conditions, has almost entirely precluded sulphur removal.

This series of samples shows that the sulphur in blast-furnace metal falls with increasing manganese content, if allowed to stand without disturbance in a slowly cooling ladle. The percentage of sulphur lost increases with increasing manganese, although the initial sulphur content is lower in the higher manganese ranges.

There are not many figures here from which to draw conclusions, but this is an example of groups of figures taken from time to time, all of which showed the same trend, although differing a little in degree.

ADDITION OF MANGANESE ORE OR FERRO-MANGANESE TO IRON

Following the investigations already recorded, efforts were made to increase the manganese content of the iron in the transfer ladle at the blast-furnaces by adding either manganese ore or ferro-manganese. It was believed that, if this could be achieved, further sulphur reduction would be possible while the metal was being transferred to the melting shop.

Three methods of adding manganese were used:

(i) By manganese ore (40%)

(ii) By ferro-manganese (80%)
(iii) By a mixture of manganese ore with coke.

These materials were added during filling the ladle at the blast-furnaces.

The first trials of manganese ore were made in open-top ladles, but were not successful. The manganese-bearing slag came to the surface as a black sticky mass and quickly set, with no important effect on the metal. If the manganese in the slag was to react with the metal, slag fluidity had to be maintained, so that only an enclosed type of ladle could be used. The metal must also be hot, and reducing conditions must be partly maintained to assist reduction of manganese from the added ore. These requirements would also be favoured by using the semi-closed ladle.

It is a general characteristic of blast-furnace practice that 'hotter' iron is lower in sulphur and higher in manganese, so that conditions most favourable to the addition of manganese to the ladle are obtained only when sufficient manganese and relatively low sulphur are present.

When ferro-manganese was added, it was also desirable to have a relatively hot iron, because this gave the best yield.

Summary

The results were neither conclusive nor promising; a sticky slag is left in the ladles, which may or may not be washed out during the next charge, with a corresponding effect on its iron analysis.

In one test, the manganese content was raised as high as 2·6%, but even this did not remove any important amount of sulphur. Sulphur was only removed appreciably when it was high, and this was generally much less than would have been expected had the same manganese been present initially in the iron. When the sulphur content was medium or low, it varied up or down, and any removal was generally less than that normally found in ladles to which no addition had been made.

The effect of the added manganese was obliterated if large amounts of blast-furnace slag passed into the ladle, or were present from a previous cast.

TREATMENT BY SCALE AND LIMESTONE

In 1940 and 1941, after preliminary work in the United Steel Companies' Research and Development Laboratories, a number of experiments on the addition of oxidizing and slag-forming materials to molten blast-furnace iron in ladles were conducted at Appleby-Frodingham. These experiments were carefully supervised, and their results were taken to be sufficiently indicative of the possibilities of routine use of the processes involved.

The first experiment was designed to cause scale to react with molten iron. As the metal ladles were of semi-closed type, scale could not be added at the blast-furnace; molten iron was therefore poured into the oxidizing agent, which was placed in an 85-ton open-top ladle, the transfer taking place in the melting-shop building, using the casting cranes.

In the first experiment, three tons (5%) of scale were put into an 85-ton ladle and iron was poured in. The transfer had to take place very slowly, as the reactions were of explosive violence. Initial slow pouring was expected to cause the scale to float, but it was in fact covered with splashes that solidified, holding the scale down on the ladle bottom and making the whole operation dangerous and liable to violent explosions. A foamy slag was produced which, when metal transfer was complete, was about 2½ ft. thick, but settled down to about 18 in. with reaction still taking place.

In the second trial, the same amount of scale was shovelled rapidly into the stream during metal transfer. The reaction seemed slow and unsatisfactory, and the slag was very thick, in appearance more like sinter than slag.

In the third test, scale was shovelled in with the iron so rapidly that it was all added when 40% of the metal had been transferred. Pouring then ceased, and 7–10 min. were allowed for the mass of material to warm up. During this time, reactions were obviously proceeding, which continually forced volcanos of slag through the covering of scale and partly formed slag. The iron ladle was then lifted 25 ft. above the metal in the open-top ladle, and the rest of the iron was transferred as quickly as possible (30 tons in less than 1 min.). A rapid reaction took place, but settled down in about 7 min., although it was not safe to approach the ladle, because of splashes, for some time longer. The slag was light and frothy, and never settled down to a free-flowing liquid. When the ladle could be approached sufficiently for the lifting gear to be attached, the slag had set on the surface; when the crust was broken, a mass of spongy slag was exuded, which would not pour off separately but ran out mixed with molten iron. It was all teemed rapidly into the mixer, and this method of treatment was used in all subsequent tests.

The general result of the preliminary tests showed that ladle reaction was still taking place 10 min. after pouring; if it were allowed to proceed longer, the slag would set into such large cakes as to block up the mixer chute.

The normal viscosity of the slag was such that when a 5-in. sample spoon was thrust below the surface, lifted out and poured on to a steel plate, it spread into a cake of no more than 8 in. dia. and ½–¾ in. thick. In appearance, it was light and frothy, and one or two samples still contained iron shot. In general, however, losses due to shot were not very apparent.

Preliminary analyses showed the iron loss to be great, and fairly consistent at these high figures. Further trials were made using fluorspar and limestone as well as scale. The results showed lime to be important in reducing the quantity of iron remaining in the slag, without materially detracting from the efficiency of the process. No method was discovered to overcome the difficulty of slag removal. Ladle-lining wear was light; in parts, there was a tendency to build up with slag.

The maximum quantity of cold additions that could be effective was apparently 5%, extra quantities merely staying with the slag without increasing the efficiency of the process.

Charging the iron-rich slag into the mixer did not increase the iron content of the mixer slag. This

Table II

RESULTS OF ADDITIONS OF OXIDIZING AND SLAG-FORMING MATERIALS TO MOLTEN IRON

Group No.*	Iron on Test, tons	Cwt./ton of Iron: Scale	Limestone	Spar†	Before Treatment: Temp., °C.	C, %	Si, %	P, %	Mn, %	S, %	After Treatment: Temp., °C.	C, %	Si, %	P, %	Mn, %	Si, %	Slag Analysis: Insol., %‡	Mn, %	P, %	CaO, %	Fe, %	Fe_2O_3, %	FeO, %
1	461	0·835	...	0·06	1203	3·71	0·89	1·56	1·11	0·063	1183	3·65	0·60	1·51	0·80	0·067	26·3	13·6	1·23	2·0	35·2	4·71	41·79
2	333	0·66	...	0·06	1210	3·52	0·70	1·66	0·94	0·073	1162	3·49	0·49	1·59	0·69	0·075	24·1	14·3	1·24	5·0	33·5	4·00	38·95
3	212	0·377	0·189	0·06	1205	3·54	0·69	1·61	0·99	0·078	1162	3·54	0·47	1·57	0·78	0·079	30·2	18·0	0·21	19·1	13·1	2·29	14·65
4	226	0·686	0·187	0·11	1205	3·65	0·70	1·61	1·00	0·069	1152	3·60	0·41	1·54	0·70	0·079	26·7	16·2	0·47	20·1	18·7	3·71	20·19

* Twenty-two casts of iron were treated: 8, 6, 4, and 4 in each group respectively
† The trials with fluorspar showed no apparent effect in removing sulphur
‡ SiO_2 in slag is about 0·75%, below insoluble figure shown

method of ladle treatment largely increased the speed of silicon removal possible with a given mixer capacity. It could not be continued, however, because a slight delay in transfer allowed the slag to set, which blocked the metal chutes.

The results are summarized in Table II. The individual ladles treated gave fairly consistent results, but since some slag and scale remained in the ladle after each treatment, each group of trials is averaged.

Table II shows that:

(i) Fluorspar had no beneficial effect when used with scale alone

(ii) Tests 3 and 4 showed the importance of limestone in reducing the iron content of the slag produced

(iii) The temperatures, taken with a disappearing filament pyrometer, showed a substantial fall during treatment

(iv) All trials showed an average increase in sulphur content of the metal

(v) The addition of limestone did not appear to reduce the manganese loss; in fact the slags from limestone-treated trials contained most manganese

Analysis of Results

The increased effectiveness of added oxide is shown as follows:

Group No.	Si and Mn Removed per Ton of Iron, cwt.	Calculated for each cwt./ton of Scale Addition
1	0·1200	0·144
2	0·0925	0·140
3	0·0860	0·229
4	0·1170	0·171

Spar does not improve the effect of scale additions, but limestone materially increases the efficiency. Group 4 shows the advantage of the limestone, and the disadvantage of adding too much cold material.

If the slag weight and the iron analysis, etc., are known, an approximate yield can be calculated by deducting, from the iron derived from the added scale, the loss in the slag and the loss of carbon, phosphorus, manganese, and silicon from the iron. The following figures show the gains expressed as a percentage of the weight of pig iron used.

Group No.	Percentage Gain
1	1·04
2	0·86
3	0·56
4	1·05

Summary

(i) There is an important fall in temperature during the treatment when it takes place as described.

(ii) The loss of iron in the slag is high, but can be reduced by additions of limestone.

(iii) The loss of iron in the slag is increased when the quantity of cold material added is above the optimum.

(iv) Reactions appear to proceed well, even with thick slags.

(v) Much turbulence must be caused when adding the iron, to give the maximum rate of reaction.

(vi) No important removal of phosphorus and carbon takes place, and sulphur tends to rise.

(vii) With iron of the analysis shown, 35% of silicon and 30% of manganese can always be removed by this process.

(viii) The difficulty of removing slag was not overcome, and, for normal production methods, would cause trouble when pouring the iron into the mixer, owing to bad splashing from lumps blocking the chute.

(ix) If slag and metal could be separated easily, the process would probably be economically successful, owing to the yield gain from added oxides, especially if the slag iron could be kept low and the slag returned to the blast-furnaces for the recovery of iron and manganese. The yield gain shown will approximately balance the cost of the ladle additions, and, if a low-iron slag could be achieved and the slag sold to the blast-furnaces, a slight gain would result. Handling and ladle costs would be high if treatment were as outlined in these tests.

(x) Little information on the loss due to iron shot was available in these trials, as all the slag was poured into the mixer. If the slag were allowed to set on the ladle, the iron poured from beneath it, and the slag knocked out into the pit, the loss due to iron shot and skull might be important.

(xi) For the process to be useful, some method must be devised to produce a fluid slag, allowing ready separation of metal and slag outside the mixer.

OXYGEN BLOWING IN MOLTEN BLAST-FURNACE IRON

A series of experiments was conducted to show the effect of blowing oxygen into blast-furnace iron held in the semi-closed transfer ladle.

Although the initial trials removed silicon, they greatly increased the sulphur content of the metal due to reversion from the slag that always seems to be present in a semi-closed ladle that has been in use for some time. This slag was apparently small in quantity, but contains enough sulphur to have an important effect on the iron, under highly oxidizing conditions.

Six trials were made in which the iron was tapped into new or almost new ladles, and was apparently free from slag. Average results were achieved as follows:

	As-Received	After Blowing
Si, %	1·0	0·3
P, %	1·55	1·60
Mn, %	1·10	0·3
S, %	0·080	0·082
C, %	3·50	3·0

The amount of oxygen needed in these tests was almost 50% more than that calculated to be necessary to remove the carbon, silicon, and manganese. As the metal was substantially free from slag, sulphur reversion was at a minimum.

The blowing time required was 1½ hr. for 50 tons of metal. The maximum rate of oxygen input, without undue splashing and danger to those holding the lance, was 500 cu. ft./min. Lance consumption (1-in. pipe) was 1 ft. per 180 cu. ft. of oxygen.

This experiment, which was conducted in the melting-shop pit, produced such dense fumes that it stopped operation of the melting-shop pit-side cranes over half the length of the building.

The iron temperature, as measured by the immersion pyrometer, rose 200–300° C., which had a material effect on the ladle life. Normally, for transfer, this is about 250 charges, but the appearance of the ladle after oxygen blowing suggested that 50 would be a maximum.

From a cost point of view, the loss of yield is important, and the total cost of blowing could be sub-divided as follows:

Loss of yield	30%
Oxygen and pipe	64%
Ladles	6%

These costs do not allow for labour, works or departmental expenses, etc.

The cost of treating iron in an active mixer to give a similar final analysis is under 75% of the cost of blowing, and this figure includes all departmental expenses, services, etc. The cost of oxygen for this trial was 11*s.* 6*d.* per 1000 cu. ft.

Treatment was discontinued because of cost, shortage of molten iron, and inability to continue in the melting shop owing to the normal crane congestion and the fumes produced.

For plants without mixers, or with mixers of inadequate capacity, this process could be economic, since the extra cost would be more than absorbed by increased steel-furnace production if the amount of molten iron to be used were high. Special apparatus would be necessary if large quantities were to be treated. The iron must be freed completely from sulphur-bearing furnace slag before oxygen blowing starts, and the fumes must be satisfactorily removed from the atmosphere of the building in which blowing is being conducted. If important quantities are to be dealt with in industrial areas, some method of fume adsorption must be incorporated in the ventilating system, to prevent the heavy brown fumes from spreading over the district.

SODA ASH

Molten iron destined for the pig-casting machine, and expected to contain more than 0·08% of sulphur, is treated with soda ash by transferring it to another ladle; it is then poured in the usual way.

ACTIVE MIXER PRACTICE

MIXER CONSTRUCTION, DESIGN, AND OPERATION

The performance of four mixers and one steel furnace-mixer are discussed in this part of the paper. They will be referred to as follows:

Mixer–Frodingham	Capacity 400 tons	Started 1916
Mixer 1	Capacity 500 ,,	Started 1927
Mixer 2	Capacity 600 tons	Started 1939
Mixer 3	Capacity 600 ,,	Started 1947
'R' Furnace Mixer		Started 1945

Some details of mixer practice were given in a previous paper by the author,* but, for convenience in reference, some of the illustrations are repeated.

History

Mixer–Frodingham, the original mixer, was built at the old Frodingham plant, which at that time had three tilting furnaces in operation, a fourth being added in 1920. The whole plant was dismantled in 1947/48.

Mixer 1 was built at Appleby, and started in 1927, when it served three 250-ton tilting furnaces. A fourth steel furnace was built in 1930, and a fifth in 1937, so that from 1927 to 1939 this one mixer served an expanding melting shop. It was redesigned in 1942.

Mixer 2 was built at Appleby in 1939 at the same time as the sixth steel furnace. A seventh steel furnace came into use in 1947, so that Mixers 1 and 2 now handle the iron for three 250-ton and four 300-ton steel furnaces.

Mixer 3 was built in 1947 with two 300/350-ton tilting furnaces to start the new Frodingham melting shop, which replaced the old plant.

GENERAL OUTLINE OF DESIGN AND CONSTRUCTION

Mixer-Frodingham

This mixer had ports similar to those shown in Figs. 1 and 2 for Mixer 1; it was similarly proportioned to these drawings, but was 100 tons smaller in designed

* A. Jackson, *J. Iron Steel Inst.*, 1949, vol. 162, pp. 136–162.

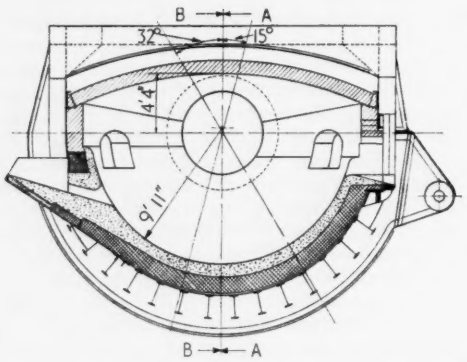

Fig. 1—Mixer 1 (500-ton): cross-section on centre-line

capacity. For most of its life it was fired with semi-cleaned or cleaned blast-furnace gas. With this fuel it could maintain a temperature high enough to melt a reasonable amount of refining additions.

The regenerators and slag pockets needed attention to remove dust more often than to replace damaged refractories. The ports contained little brickwork, so that repair costs were small. The only water cooling was on horizontal chills, which formed the joint between the uptake and the movable port. These ports were withdrawn 2–3 in. from the furnace end, to allow tilting without friction, and access of some air to cool the steelwork near the port and furnace ends. The blocks were only moved back during repairs.

The main roof and linings lasted well. Most wear was found in the hearth under the metal-charging doors and round the banks. This was the usual reason for taking off the furnace for annual repairs. The roof life often exceeded one year, but the roof was not left on unless it appeared safe for another year. It was sometimes removed to facilitate repair to the hearth and linings, or because of distortion caused by heating and cooling, which left it rather unsafe to work under.

The mixer was charged from and tapped into 30-ton open-top ladles on the pitside. One ground-type charger, on the opposite side, charged boxes from bogies brought in on rails in front of the furnace. These bogies were loaded from wagons just beyond the end of the mixer, and were shunted as needed by the charging machine. Slag was poured into 7-ton pans on the charging side.

In 1940, coke-oven gas became available, and small quantities were passed into the furnace with the blast-furnace gas. The ports were slightly redesigned within the limits of the steel structural work, thus increasing the melting capacity.

In 1944, the charging arrangements were modified: the bogies were filled in the building used for loading the open-hearth material, and this, with the small added heat resulting from coke-oven gas, allowed a certain amount of low-grade scrap to be melted.

The figures for the working of this mixer are shown in Table III. They show that this old mixer, although doing excellent work, could not compete in melting capacity and silicon removal with the more modern types.

Mixer 1

Details of Mixer 1 are shown in Figs. 1 and 2; in many ways it was similar in design to the Frodingham mixer, but was slightly larger. As well as being fired with blast-furnace gas, it was on the main producer-gas line of the steel furnaces, and so could easily change over to producer gas if its normal fuel was in short supply. It was therefore restricted less than the Frodingham mixer by blast-furnace breakdowns, which reduced the available gas supply.

Until mid-1939, it worked the Appleby shop alone, and the figures show some very good average weekly productions. The rate of feeding per ton of iron produced appears to be low, but the quantity charged in tons per week was good if the type of fuel used, and the amount of work, *i.e.*, iron in and out, is considered.

It could not be maintained at the high temperature that is usual in present-day practice. Its life was good, and it generally needed most repairs round the banks and bottom, although the linings needed more repairs than the old Frodingham type ; the roof was usually renewed each year because it was not safe to work under, but otherwise it would often have lasted for two years.

In 1942, this mixer was redesigned to give ports similar to those shown for Mixers 2 and 3, or those on the more modern steel furnaces. The uptakes were

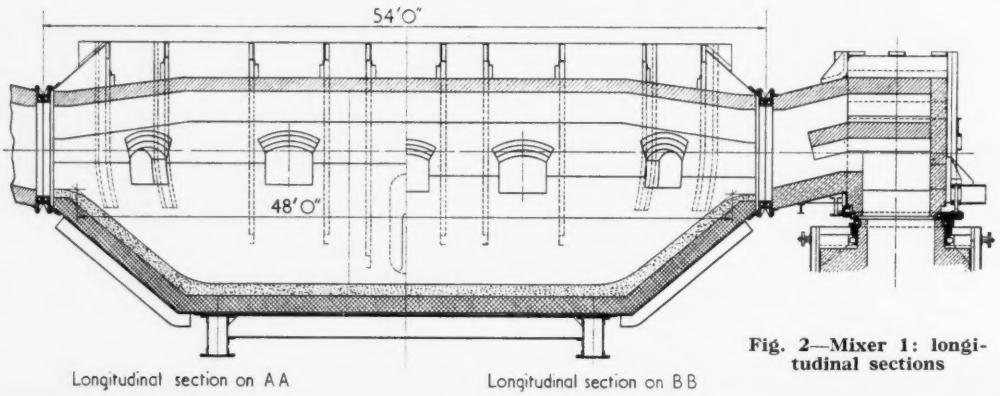

Fig. 2—Mixer 1: longitudinal sections

Table III

RECORDS OF BATH ADDITIONS TO MIXERS FRODINGHAM AND 3

	Skulls and Cold Iron	Scrap	Production	Ox-ides	Lime-stone	Skulls	Iron-stone	Slag	Iron In				Iron Out				Slag Analysis										
	Cwt./ton								P, %	Mn, %	Si, %	S, %	P, %	Mn, %	Si, %	S, %	SiO_2, %	Al_2O_3, %	CaO, %	MnO, %	Mn, %	MgO, %	P_2O_5, %	P, %	Total Si, %	FeO, %	Fe_2O_3, %	Total Fe, %
Mixer–Frodingham																											
1937 Jan.–June																	33 62	5 87	30 66	14 46	11 13	5 45	1 81	0 80	0 303	7 25	1 31	6 55
,, July–Dec.																	33 34	5 98	30 93	15 62	12 18	5 51	1 66	0 74	0 28	5 81	1 05	5 21
1938 Jan.–June																	32 87	6 57	30 60	14 80	11 40	5 66	1 89	0 832	0 24	6 56	1 12	5 88
,, July–Dec.																	30 70	6 40	31 40	16 46	12 67	4 35	2 67	1 15	0 21	6 70	1 43	6 20
1939 Jan.–June																	32 80	5 30	33 80	12 695	9 775	5 305	2 10	0 925	0 20	6 945	1 035	6 125
,, July–Dec.																	31 05	5 34	36 26	12 65	9 74	4 75	2 11	0 93	0 203	6 94	0 98	6 10
1940 Jan.–June																	32 05	6 23	35 63	10 44	8 04	5 16	1 86	0 82	0 165	7 62	1 57	7 00
,, July–Dec.																	30 46	5 12	33 77	11 64	8 52	3 96	2 72	1 29	0 18	8 96	2 14	8 47
1941 Jan.–June																	34 30	3 87	32 23	12 70	9 13	5 26	2 24	0 99	0 19	6 94	1 33	6 33
,, July–Dec.																	31 30	3 94	30 76	15 61	11 25	4 85	2 95	1 17	0 20	8 46	1 76	7 78
1942 Jan.–June																	32 33	2 77	38 50	10 59	7 63	5 75	1 29	0 57	0 22	5 81	1 45	5 70
,, July–Dec.																	31 30	3 21	34 10	13 96	10 05	5 39	1 85	1 25	0 22	6 53	2 29	6 15
1943 Jan.–June																	30 80	3 41	34 90	11 87	8 67	5 73	3 03	1 33	0 22	6 53	2 32	6 70
,, July–Dec.																	30 85	4 19	34 03	11 87	8 67	4 58	2 69	1 27	0 15	8 89	2 50	8 55
1944 Jan.–June																	30 64	3 73	37 30	12 14	9 35	4 76	2 56	1 13	0 13	5 90	2 37	5 90
,, July–Dec.																	30 44	3 70	37 50	11 09	8 54	5 54	2 88	1 17	0 124	5 50	3 92	7 00
1945 Jan.–June																	29 96	3 47	38 60	9 80	7 55	7 09	2 65	1 17	0 176	4 38	2 36	6 10
,, July–Dec.	0 06	1 37	2431	0 57	0 47	0 24		0 71	1 53	1 13	0 89	0 062	1 42	0 75	0 35	0 053	29 01	2 65	39 20	9 39	7 23	6 46	3 62	1 24	0 141	6 13	2 45	6 40
1946 Jan.–June		1 39	3237	0 55	0 55	0 34		0 70	1 52	1 13	0 84	0 065	1 37	0 75	0 36	0 061	29 75	2 65	39 20	9 39	7 23	6 37	3 52	1 55	0 180	6 97	2 95	7 50
1947 Jan.–June		1 56	2851	0 50	0 55	0 71		0 74	1 52	1 14	0 94	0 080	1 29	0 67	0 42	0 070	27 76	2 78	38 50	7 93	6 14	4 15	6 58	2 90	0 155	7 07	2 64	7 4
,, July–Dec.	0 01	1 73	3122	0 75	0 72	0 29		1 04	1 52	1 08	0 96	0 073	1 29	0 67	0 34	0 067	28 55	2 78	38 50	7 93	6 14	4 15	6 58	2 90				
Mixer 3																												
1948 Jan.–June	0 12	2 02	3346	1 01	1 13	0 10		1 81	1 52	0 95	1 10	0 084	1 16	0 48	0 23	0 073	27 49	2 66	40 70	8 06	6 25	4 96	5 62	2 47	0 200	6 60	2 29	6 7
,, July–Dec.	0 17	1 88	3450	0 99	1 09	0 14		1 68	1 52	0 99	1 09	0 085	1 18	0 51	0 25	0 077	27 76	2 66	40 70	8 15	6 32	4 66	5 15	2 51	0 236	7 03	2 05	6 9
1949 Jan.–June	0 14	2 19	3304	1 12	1 14	0 10		1 75	1 54	1 03	1 00	0 076	1 17	0 49	0 24	0 070	27 93	2 62	39 20	8 35	6 01	4 02	5 71	2 51	0 176	7 16	2 70	7 6
,, July–Dec.	0 11	1 93	3735	1 15	1 13	0 07		1 57	1 55	0 99	1 00	0 069	1 20	0 45	0 23	0 063	27 93	2 62	39 20	8 35	6 63	4 33	5 76	2 49	0 151	6 95	2 95	9 4
1950 Jan.–June	0 68	1 79	3625	0 96	1 00	0 12		1 55	1 51	1 01	0 88	0 069	1 14	0 45	0 20	0 070	27 76	2 70	38 70	8 43	6 79	4 06	6 82	2 49	0 151	6 95	3 26	7 9
,, July–Dec.	0 17	2 32	3744	0 93	1 09	0 10		1 62	1 55	1 01	1 02	0 082	1 15	0 43	0 20	0 070	27 24	3 03	39 20	8 98	6 96	4 16	7 49	3 00	0 121	6 88	2 04	7 9
1951 Jan.–June	0 21	2 22	3459	0 83	1 10	0 13		1 70	1 55	0 99	1 06	0 094	1 17	0 44	0 23	0 082	26 97	2 96	38 50	8 88	6 87	3 93	7 96	3 53	0 173	7 59	2 15	7 4

also rebuilt, and the structure of the furnace body was opened out at the ends from its original cone-shape to give a design similar to that of the steel furnaces. This materially increased its melting capacity, and enabled it to assist in satisfactorily handling the increased silicon in the iron from the blast-furnaces.

Mixer 2

This mixer was built in 1939, and the design is shown in Figs. 3 and 4. Apart from bath depth and the general construction of the moving part of the furnace, it is identical with that of the 300/350-ton steel furnace, the blocks, chills, valves, etc., being interchangeable. It was designed to be fired with mixed blast-furnace and coke-oven gas, and is instrumented as for a steel furnace.

Mixer 3

This mixer was built with the new Frodingham steel plant in 1947, and is identical in design with Mixer 2. It is fully instrumented, with automatically controlled air/gas ratio and constant furnace pressure. At present it serves only two steel furnaces, but it is expected to do more when the plant is extended.

Mixers 1, 2, and 3 are all now modified to enable them to be fired with creosote pitch should there be a shortage of blast-furnace or coke-oven gas.

'R' Furnace Mixer

This was built as a 300/350-ton steel furnace, almost exactly similar to the furnaces built on Frodingham (South) Melting Shop in 1947.* It is fully instrumented, and uses the same fuel as steel furnaces.

Plans for building this furnace were made early in the war, when it was expected that conditions would necessitate cold-charged fixed furnaces using higher percentages of iron than their optimum. It was designed to be used as a mixer to refine North Lincolnshire iron, thus minimizing the impact of increasing percentages of cold iron on the production rate of cold-charged fixed furnaces.

Owing to delay caused by wartime conditions, and the fact that scrap did not become as scarce as expected, the furnace was not finished until 1945. In

* A. Jackson, *loc. cit.*

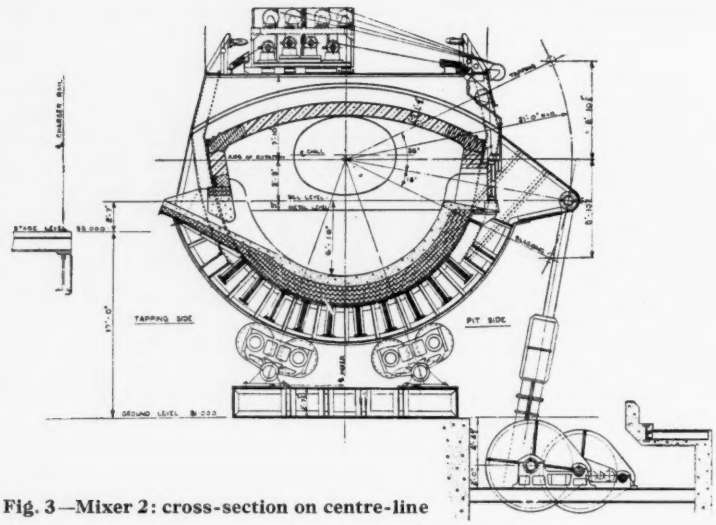

Fig. 3—Mixer 2: cross-section on centre-line

spite of the adequate scrap then available, it was decided that, for a trial period, this furnace should be used as a mixer as originally designed, and the economics of the process would be considered. It operated for about a year in 1945/6; after the operating conditions had been determined, and with increasing demand for steel ingots in the mill, it was used as a steel furnace.

The process used in 'R' Mixer differs specifically from normal Appleby-Frodingham practice in that it was worked to a time and analysis schedule, whereas all other mixers work continuously charging and discharging.

The two Appleby Mixers (1 and 2) have operated with alternate charging, refining and tapping schedules, but the method was unsatisfactory because of the working of the shop and the disposition of the mixers; *i.e.*, when Mixer 2 is emptying, metal has to travel a quarter of a mile to *K* furnace, and only slightly less travelling is necessary when Mixer 1 is emptying.

Experience also shows that more silicon can be removed by two mixers working independently than by alternate refining and emptying. The latter method has the advantage of giving uniform quality of mixer output, but this is unimportant when slag control is used on the steel furnaces, as the composition of the charge can be varied with the analysis of the iron from the mixers.

REFRACTORY CONSTRUCTION OF MIXERS

To a little above sill level, the hearth is magnesite. Above the maximum metal and slag level, the lining, arches, and roof are all silica. The blocks, uptakes and slag pockets are of the same material and, like the furnace roof, are all insulated.

The magnesite brick hearth is lined with stable dolomite bricks, 9 in. thick at the bottom and tapering to 3 in. at sill level. On this, tarred dolomite is rammed and burned in.

The average mixer life is 12–15 months for top repair, which comprises repairs to the lining and sometimes to the roof, facing the blocks, and removing the small quantity of slag from the pockets and flues. Every two years, the magnesite banks have to be taken down to 3 or 4 ft. below sill level, the upper part of the blocks rebuilt, and possibly the upper rows of the checkers replaced, as well as the normal minor repairs to be made.

FUEL CONSUMPTION

Gas consumption is now 450–500 therms/hr., compared with 575–625 therms/hr. in the steel furnaces. For comparison, the old Frodingham mixer used 300 therms/hr. when it was fired with blast-furnace gas.

The following figures show the fuel consumption at characteristic periods over the years discussed. They are based on three months' average in each case.

Mixer	Fuel Used	Consumption, therms/hr.
Frodingham	1939—blast-furnace gas	300
	1943—blast-furnace with a little coke-oven gas	350
1	1939—blast-furnace gas only	320
	1940—blast-furnace with coke-oven gas as required	495
	1951—mixed blast-furnace and coke-oven gas	450
2	1951— ,, ,, ,, ,,	500
3	1951— ,, ,, ,, ,,	500

EFFECT OF IRON QUALITY ON DESIGNED MIXER CAPACITY

Experience and experimental evidence have shown that an active mixer cannot remove large percentages of silicon and sulphur together, so that mixer design, to be most effective in a given instance, must be based on a knowledge of the analysis of the iron to be charged, and the product required, *i.e.*, whether it is desired to remove large quantities of silicon or sulphur, or a modest amount of both.

Early active mixers were designed to have what was then considered to be high capacity. They were also expected to burn only enough fuel to prevent the iron from cooling seriously while waiting for transfer to the steel furnaces. Small amounts of scale were added, and lime-bearing materials were needed to prevent attack on the banks by the silicon oxidized.

During the last 30 years, active mixers everywhere have been called upon to take a greater part in steelmaking operations than was expected when they were designed and built. These old mixers were often over 6 ft. deep, and their main duty was to mix and store metal from the blast-furnaces until required for the steel furnaces. Aided by small feeds of limestone, limey iron ore, and oxides, they often showed a reduction of 40% of sulphur and up to 30% of silicon, provided that the iron contained over 1·0% of manganese and was relatively undisturbed by

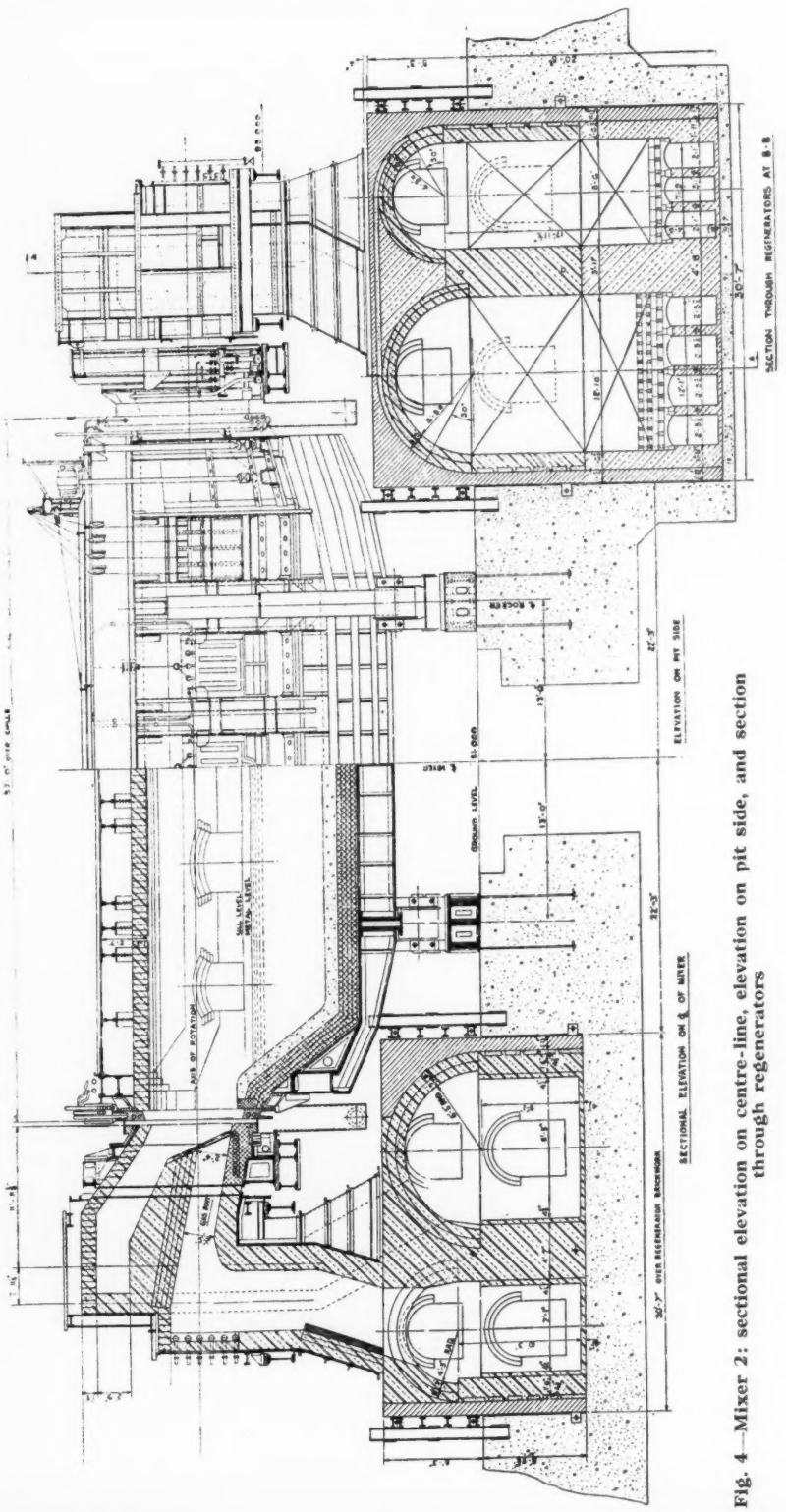

Fig. 4—Mixer 2: sectional elevation on centre-line, elevation on pit side, and section through regenerators

additions of oxide and limestone during its stay in the mixer. This modest feeding was limited by skull formation in the outgoing transfer ladle.

High-Silicon Iron

This term refers not only to the silicon in the iron, but also to the amount relative to the desired analysis on leaving the mixer; *e.g.*, if an outgoing silicon content of 0·3% were required, 1·1% would be considered high and 0·6% low.

It is more difficult to remove silicon in quantity when the mixer is full than when it is low; furthermore, if it is kept full of siliceous iron for a day or two, the banks will be found to be seriously damaged when the level is lowered.

The reasons for difficulty in removing silicon from a mixer kept near its full capacity are:

(i) The metal bath is very deep, and therefore inactive, so that reaction takes place only on the surface layers

(ii) Feeding usually causes foaming, with consequent spillage, round the furnace; the 'mess' produced deters further feeding.

With high-silicon iron, it is better to work the mixer at about two-thirds capacity. This allows heavier feeding and room to melt. The addition of further iron promotes an immediate reaction, but the remaining mixer capacity is enough to prevent overflow. The reduction in capacity reduces the storage available to the steel furnaces, and will probably give wider fluctuation in the outgoing metal, although slag control should counteract this, if properly applied.

A deep mixer, using high-silicon iron, will be troublesome to maintain,

owing to the difficulty of fettling the high banks without at the same time materially reducing its capacity by thickening the bottom. Taphole trouble is frequent, owing to the difficulties of maintenance, and allows slag to pass to the steel furnaces with the metal.

Low-Silicon Iron

This type of iron is generally higher in sulphur. As little feeding is required, the mixer may be large, and kept almost full. There is less damage to banks, because neither silicon nor oxides are present in sufficient quantity to give rapid attack. Furthermore, there is no necessity to drive in heat to melt large amounts of feed; sulphur flotation is, in fact, aided by steady cooling.

When sulphur is high, the greatest reduction is achieved by allowing the iron to stand with minimum agitation. These conditions are achieved in a large mixer kept as full as possible, thus allowing maximum mixing and standing time.

Mixer Capacity

If a mixer is to remove large amounts of silicon, it should be fairly small, *e.g.*, 400 tons capacity. The difficulties of operation are:

(i) Much fettling will be needed, which is difficult with depths above 4 ft., as the banks cannot be maintained at slag level without undue thickening at the bottom

(ii) If the slag line is undermined, the linings will collapse, and the mixer will need major repairs too often

(iii) Slag depth must be minimized by frequent removal, otherwise serious foaming will occur whenever feeding takes place

(iv) The rate of hearth wear will necessitate frequent emptying for major fettling. This is easy in a small mixer, which can be emptied in charging two or three steel furnaces. It is then rapidly fettled, and can be back at work before these furnaces are again ready to charge. Emptying a large mixer becomes a problem of organization if it is not to interfere unduly with steel output

(v) A shallow bath enables the metal to be raised to a higher temperature to compensate for the increased melting point due to the lower silicon content.

Summary

Low-silicon–high-sulphur iron can be best treated in a relatively large, or completely inactive, mixer, but if rapid silicon removal is paramount, mixer design should be similar to that of a 400-ton steel furnace.

MIXER FEEDING METHODS

Use of Local Basic Stone

For many years before 1939, a large proportion of the oxidizing additions to the mixers were of local basic ironstone. This was selected carefully from certain parts of the local ore beds, and maintained a relatively regular analysis, similar to that shown in the following six months' average in 1937:

Moisture	11·0%	Manganese	1·0%
Silica	6·8%	Phosphorus	0·4%
Lime	20·0%	Sulphur	0·34%
Magnesia	1·8%	Combined CO_2 and moisture	23%
Alumina	4·5%		
Iron	18·0%		

During the same period, mixer slag analysis was:

Silica	32·0%	Iron	6·5%
Lime	31·0%	Manganese	11·15%
Magnesia	5·5%	Phosphorus	0·80%
Alumina	5·5%	Sulphur	0·30%

The basic stone was satisfactory for mixer feed when firing was by blast-furnace gas alone, because the material was easily fluxed to form a fluid slag. Its manganese content was believed to be of advantage, and the mixer slag was returned to the blast-furnaces.

Later, the stone received by the melting shop became generally more acid and more variable in analysis, containing increasing numbers of very large lumps. This was due to the increased quantities mined by blasting and mechanical diggers, which meant that it was less possible to select and segregate the ore bed suitable for mixers.

War conditions increased these difficulties, and by 1944 the stone was often so acid that, as well as fluxing easily, it seemed to cut the mixer banks rapidly, thus materially increasing the amount of fettling required. Supply became very irregular, so that in 1944 arrangements were made to substitute limestone and oxides for the basic ironstone, the general aim being to produce the same amount of slag as before.

The cost of using basic stone was slightly less per ton of iron treated, but as supplies that were satisfactory both physically and chemically could not be obtained with the prevailing methods of mining, limestone and oxide were introduced to replace basic stone completely for feeding. For several intermediate years, all these materials were used, the relative quantities depending on the availability of basic ironstone.

Mixer Feeding Methods

The figures in Tables III and IV show the changes made in bath additions over about 15 years.

Before 1940, fairly small additions of basic stone, with a little oxide and limestone when necessary, were added to keep the bath covered. These additions could be easily melted and later removed as slag. Cold pig and occasionally a little scrap were added, the former to balance shortages of iron, and the latter to use small quantities of material considered to be too rough or too dirty for the steel furnaces. In all, 1·0–1·3 cwt. of cold material were charged per ton of iron, and even with these small additions the ladle skull produced in the transfer ladles was appreciable, as shown in the Tables.

In 1940, further pressure was put on to increase mixer feeding, and the amount of cold material added per ton of iron was 1·5–2·0 cwt./ton of charged metal, this increase being maintained in spite of increased throughputs of molten iron.

Similar quantities were substantially maintained until 1942, when Mixer 1 was redesigned to increase its ability to melt cold materials. Subsequent results show that these could have been increased further, but, at the time, the general opinion of those operating the mixers was that they were doing better than any mixer had ever done before.

The smaller quantity of oxidizing additions used at this time resulted from the method of feeding in

Table IV

RECORD OF BATH ADDITIONS TO MIXERS 1 AND 2

	Skulls and Pig Iron	Scrap	Production	Oxides	Iron-stone	Lime-stone	Skulls	Slag	Iron In				Iron Out				Slag Analysis										
	Cwt./ton								P, %	Mn, %	Si, %	S, %	P, %	Mn, %	Si, %	S, %	SiO_2, %	Al_2O_3, %	CaO, %	MnO, %	MgO, %	P_2O_5, %	Mn, %	Total S, %	FeO, %	Fe_2O_3, %	Total Fe, %
Mixer 1																											
1937 Jan.–June	0·85	0·22	5669	0·46	0·36	0·16	0·18	0·82	1·58	1·43	0·66	0·087	1·44	0·86	0·29	0·070	30·13	5·30	27·07	19·52	15·03	4·11	3·41	1·50	0·365	8·89	8·00
July–Dec.	0·32	0·91	6397	0·35	0·32	0·16	0·12	0·66	1·49	1·34	0·55	0·089	1·31	0·76	0·29	0·074	28·68	4·99	27·51	20·01	15·41	4·36	3·74	1·61	0·34	8·95	8·13
1938 Jan.–June	0·25	0·97	6468	0·07	0·55	0·05	0·15	0·57	1·48	1·19	0·62	0·091	1·32	0·80	0·36	0·074	31·02	6·50	29·67	14·65	11·28	5·06	2·38	1·04	0·314	9·40	8·07
July–Dec.	0·47	0·44	5590	0·11	0·56	0·10	0·28	0·69	1·45	1·28	0·61	0·089	1·27	0·81	0·36	0·069	30·41	6·40	30·50	14·59	11·22	4·94	2·79	1·23	0·263	7·35	7·88
1939 Jan.–June	0·92	0·24	6690	0·26	0·38	0·13	0·23	0·58	1·55	1·21	0·66	0·089	1·36	0·72	0·29	0·074	29·98	6·48	28·03	15·70	12·09	4·40	2·83	1·25	0·40	0·81	1·73	9·62
July–Dec.	0·27	0·51	4320	0·58	0·68	0·20	0·12	1·11	1·55	1·21	0·78	0·084	1·33	0·62	0·33	0·062	29·51	5·76	30·52	15·05	11·59	4·41	3·50	1·54	0·21	9·49	1·77	8·62
1940 Jan.–June	0·09	0·36	3962	0·48	0·83	0·23	0·09	1·26	1·55	1·27	0·83	0·077	1·36	0·74	0·31	0·062	29·40	5·61	34·33	12·17	9·37	4·40	3·13	1·39	0·13	8·70	2·40	8·44
July–Dec.	0·14	0·23	3845	0·47	0·74	0·27	0·11	1·18	1·56	1·21	0·81	0·079	1·40	0·73	0·31	0·064	28·95	5·27	34·45	11·65	8·39	4·83	3·53	1·55	0·16	7·66	2·93	7·98
1941 Jan.–June	0·24	0·07	4025	0·60	0·40	0·48	0·08	1·15	1·60	1·17	0·79	0·082	1·44	0·68	0·29	0·068	27·57	3·25	34·55	12·33	8·88	5·26	5·06	2·23	0·187	7·52	3·36	8·53
July–Dec.	0·120	0·242	3535	0·55	0·48	0·40	0·08	1·08	1·60	1·14	0·79	0·083	1·41	0·63	0·29	0·067	27·98	2·78	35·36	12·32	8·87	5·41	5·23	2·30	0·157	7·21	2·48	7·63
1942 Jan.–June	0·08	0·15	3416	0·60	0·35	0·47	0·02	0·97	1·54	1·00	0·83	0·091	1·40	0·61	0·30	0·071	30·81	2·67	37·6	9·87	7·12	6·10	2·02	0·89	0·15	6·65	2·68	7·05
1943 Jan.–June	0·12	1·19	3996	0·40	0·32	0·37	0·08	0·89	1·52	1·00	0·75	0·091	1·31	0·63	0·26	0·071	27·95	2·81	37·57	11·01	7·93	5·79	4·55	2·00	0·14	5·62	3·12	6·55
July–Dec.	0·16	2·03	3678	0·54	0·28	0·48	0·09	1·04	1·49	0·94	0·84	0·093	1·19	0·57	0·29	0·074	28·25	3·06	36·00	10·82	7·90	5·94	4·88	2·15	0·18	6·32	2·93	7·00
1944 Jan.–June	0·33	2·12	4231	0·51	0·02	0·57	0·09	0·83	1·47	1·16	1·02	0·070	1·24	0·71	0·38	0·056	28·40	3·43	37·20	10·90	8·39	5·07	4·58	2·02	0·116	5·53	3·62	6·80
July–Dec.	0·24	2·35	3960	0·42	0·01	0·64	0·08	0·90	1·49	1·09	1·00	0·071	1·23	0·71	0·32	0·056	28·60	2·38	41·20	9·32	7·18	5·34	4·56	1·57	0·102	4·53	4·08	6·80
1945 Jan.–June	1·21	1·87	3740	0·63		0·74	0·06	1·02	1·55	1·00	0·99	0·073	1·28	0·61	0·30	0·063	28·84	2·46	39·70	9·66	7·44	5·44	4·04	1·78	0·112	5·28	3·67	6·70
July–Dec.	0·26	2·20	3465	0·56		0·69	0·07	0·94	1·49	0·99	1·02	0·072	1·22	0·61	0·34	0·062	29·09	2·83	36·80	9·61	7·40	5·46	4·76	2·10	0·153	5·83	4·06	7·40
1946 Jan.–June	0·15	1·45	4409	0·57		0·57	0·08	0·86	1·50	1·06	0·95	0·068	1·28	0·65	0·33	0·058	30·44	2·56	35·20	10·00	7·70	5·43	3·98	1·73	0·178	7·05	3·61	6·8
July–Dec.	0·14	1·68	3878	0·62		0·67	0·05	0·94	1·51	1·03	0·99	0·072	1·26	0·63	0·31	0·058	31·40	2·72	35·30	10·50	8·09	5·27	3·96	1·63	0·151	6·58	2·38	6·8
1947 Jan.–June	0·31	2·06	4122	0·76		0·80	0·10	1·20	1·52	1·04	1·05	0·074	1·17	0·52	0·31	0·065	27·58	2·75	38·1	9·29	7·15	4·51	4·83	2·13	0·177	7·72	3·83	8·3
July–Dec.	0·13	1·95	4305	0·70		0·76	0·04	1·12	1·50	1·08	0·96	0·068	1·16	0·54	0·27	0·062	26·97	2·65	36·9	10·46	8·04	4·10	5·68	2·50	0·142	7·36	3·97	8·3
1948 Jan.–June	0·22	1·57	4852	0·85		0·73	0·06	1·35	1·50	1·10	0·98	0·080	1·13	0·50	0·26	0·069	25·47	2·66	36·40	10·78	8·36	5·24	6·01	2·64	0·167	8·43	3·06	8·7
July–Dec.	0·16	1·67	4723	0·79		0·71	0·57	1·37	1·53	1·12	0·93	0·087	1·11	0·49	0·23	0·073	24·65	2·64	36·6	11·66	9·04	4·70	7·16	3·15	0·230	8·48	2·45	8·2
1949 Jan.–June	0·15	1·79	4729	0·87		0·77	0·09	1·41	1·57	1·15	1·03	0·082	1·11	0·46	0·24	0·071	25·74	2·61	35·6	11·11	7·80	4·22	7·37	3·24	0·172	8·67	2·95	8·8
July–Dec.	0·08	1·73	4864	0·93		0·82	0·08	1·44	1·53	1·05	1·00	0·082	1·12	0·43	0·24	0·071	26·63	2·35	36·4	10·58	8·20	4·49	7·35	3·23	0·177	8·38	2·61	8·2
1950 Jan.–June	0·47	1·37	5078	0·66		0·70	0·09	1·28	1·50	1·05	0·88	0·086	1·16	0·49	0·24	0·078	26·60	2·71	37·3	10·33	7·44	4·08	6·26	2·75	0·231	9·05	2·06	8·1
July–Dec.	0·15	1·46	4936	0·71		0·78	0·07	1·38	1·52	1·07	0·97	0·086	1·20	0·56	0·30	0·074	28·19	3·41	37·8	9·58	7·43	3·69	5·58	2·57	0·205	8·33	1·93	7·7
1951 Jan.–June	0·17	1·47	4804	0·78		0·82	0·16	1·57	1·52	1·04	1·02	0·090	1·18	0·47	0·27	0·079	27·34	2·89	37·5	9·25	7·17	3·66	6·70	2·97	0·200	9·21	2·16	8·5
Mixer 2																											
New Furnace																											
1939 July–Dec.	0·28	0·61	4263	0·30	0·81	0·29	0·11	1·04	1·56	1·26	0·87	0·075	1·34	0·72	0·31	0·057	29·22	5·36	36·56	11·24	8·65	5·93	3·12	1·37	0·14	6·71	2·17	6·74
1940 Jan.–June	0·08	0·39	4088	0·33	0·91	0·28	0·09	1·23	1·54	1·26	0·84	0·077	1·40	0·77	0·29	0·057	31·75	6·21	34·67	12·13	9·26	4·51	2·22	0·975	0·13	6·23	1·52	6·00
July–Dec.	0·13	0·08	3850	0·25	0·65	0·33	0·15	0·95	1·57	1·15	0·77	0·082	1·42	0·76	0·29	0·060	32·53	5·13	34·73	11·75	8·46	4·59	2·30	1·01	0·13	6·71	1·40	6·30
1941 Jan.–June	0·12	0·14	3469	0·38	0·61	0·55	0·25	1·13	1·61	1·18	0·80	0·084	1·47	0·73	0·26	0·057	30·26	3·49	40·44	8·74	6·29	5·51	2·86	1·26	0·12	5·22	2·22	5·62
July–Dec.	0·10	0·82	4140	0·29	0·66	0·41	0·08	1·09	1·60	1·14	0·78	0·084	1·39	0·66	0·26	0·060	29·09	2·93	36·33	11·86	8·44	5·17	5·00	2·20	0·143	5·85	2·47	6·30
1942 Jan.–June	0·05	0·08	5241	0·45	0·35	0·39	0·04	0·92	1·55	0·99	0·77	0·095	1·43	0·64	0·29	0·069	31·25	2·86	36·60	12·33	8·88	5·29	2·42	1·06	0·14	6·56	1·98	6·21
July–Dec.	0·07	1·03	3926	0·33	0·38	0·38	0·08	0·89	1·52	1·01	0·73	0·091	1·33	0·65	0·24	0·066	30·90	3·23	36·10	12·25	8·82	5·90	3·23	1·44	0·14	5·08	2·81	5·92
1943 Jan.–June	0·06	1·73	4089	0·54	0·41	0·41	0·09	1·08	1·49	0·96	0·86	0·091	1·20	0·54	0·28	0·073	27·81	3·22	34·67	12·48	9·11	5·33	4·91	2·16	0·15	7·05	3·38	7·83
July–Dec.	0·07	1·66	5135	0·56	0·40	0·46	0·10	1·07	1·48	1·02	0·94	0·081	1·19	0·58	0·31	0·065	29·66	3·06	37·83	11·15	8·14	5·59	3·87	1·70	0·125	6·00	2·95	6·75
1944 Jan.–June	0·08	2·21	4102	0·60	0·29	0·49	0·10	0·86	1·47	1·12	1·03	0·068	1·24	0·69	0·37	0·056	29·00	3·68	36·90	10·87	8·37	4·55	4·39	1·93	0·115	6·17	3·57	7·00
July–Dec.	0·06	2·37	3532	0·72	0·01	0·73	0·09	0·90	1·49	1·11	1·00	0·070	1·23	0·65	0·33	0·057	29·60	2·23	36·90	11·91	9·17	5·14	4·01	1·76	0·097	5·10	4·23	7·10
1945 Jan.–June	0·03	1·88	3558	0·81		0·88	0·06	1·03	1·55	1·00	0·99	0·073	1·27	0·56	0·26	0·062	29·29	2·68	38·30	8·67	6·68	6·46	4·03	1·77	0·115	5·91	3·60	7·00
July–Dec.	0·21	2·08	3573	0·64		0·80	0·07	0·97	1·48	1·00	1·00	0·073	1·20	0·60	0·29	0·058	29·90	2·90	37·40	8·00	6·16	4·99	3·69	1·62	0·151	5·96	3·67	7·40
1946 Jan.–June	0·11	1·58	4148	0·58		0·72	0·07	0·91	1·51	1·08	0·92	0·068	1·25	0·63	0·29	0·057	31·61	2·62	35·50	11·09	8·54	4·46	4·05	1·78	0·194	6·66	2·69	7·10
July–Dec.	0·08	1·55	4556	0·69		0·63	0·05	0·90	1·51	1·03	1·00	0·072	1·26	0·64	0·33	0·060	31·80	2·69	37·50	9·37	7·21	4·58	3·36	1·48	0·152	6·19	2·84	6·9
1947 Jan.–June	0·12	1·87	4518	0·74		0·74	0·07	1·09	1·51	1·04	1·01	0·078	1·16	0·50	0·30	0·069	27·52	2·77	38·4	8·61	6·63	4·89	5·15	2·27	0·172	8·36	2·63	8·4
July–Dec.	0·05	1·73	4284	0·61		0·70	0·05	1·08	1·50	1·08	0·96	0·069	1·19	0·55	0·26	0·069	27·18	2·65	37·2	10·17	7·83	4·92	5·60	2·46	0·144	7·35	3·07	7·9
1948 Jan.–June	0·02	1·65	5010	0·77		0·73	0·06	1·30	1·50	1·10	1·00	0·081	1·15	0·53	0·26	0·069	26·58	2·67	37·0	10·38	8·05	5·51	5·76	2·53	0·167	7·85	2·43	7·8
July–Dec.	0·03	1·37	5041	0·70		0·67	0·05	1·24	1·51	1·13	0·97	0·086	1·17	0·54	0·27	0·069	26·25	2·66	38·5	10·92	8·46	4·72	5·84	2·57	0·203	7·28	2·05	7·2
1949 Jan.–June	0·10	1·74	4748	0·83		0·76	0·09	1·40	1·53	1·05	1·03	0·084	1·17	0·49	0·26	0·070	26·83	2·58	35·7	11·49	8·27	4·32	6·24	2·75	0·165	8·51	2·60	8·6
July–Dec.	0·14	1·54	4850	0·86		0·83	0·08	1·43	1·52	1·08	0·99	0·084	1·21	0·55	0·28	0·074	27·88	3·27	38·1	9·56	7·43	4·46	5·90	2·60	0·163	8·34	1·88	7·8
1950 Jan.–June	0·57	1·10	5414	0·76		0·75	0·10	1·32	1·49	1·07	0·90	0·087	1·17	0·50	0·26	0·075	26·70	2·66	37·9	9·57	6·89	4·16	6·32	2·78	0·209	9·06	2·05	8·3
July–Dec.	0·28	1·22	5284	0·76		0·83	0·08	1·43	1·52	1·08	0·99	0·084	1·21	0·55	0·28	0·074	27·88	3·27	38·1	9·56	7·43	3·62	5·90	2·60	0·163	8·34	1·88	7·8
1951 Jan.–June	0·47	1·12	5161	0·85		0·90	0·16	1·63	1·52	1·04	1·03	0·089	1·21	0·51	0·30	0·077	27·19	2·94	38·9	9·30	7·22	3·89	6·59	2·93	0·187	8·23	2·09	8·2

use, the quantities added being in accordance with a scale based on the following system:

> Samples were taken from the mixer at three-hourly intervals, and when the silicon content was known, additions were made according to the figures below, which show the number of boxes of material to be added for each range of silicon. The actual quantities used obviously had to be varied in accordance with the mixer throughput at any period. The following is a typical example:

Si Content, %	Scale, boxes	Basic Stone, boxes	Limestone, boxes
Up to 0·15	Nil	2	Nil
0·16–0·25	Nil	3	Nil
0·26–0·35	1	4	Nil
0·36–0·45	2	5	1
0·46 and over	3	6	2

With heavy feeding, some limestone must be added, since the stone itself is not sufficiently basic to take up the extra silicon oxidized.

The sole aim of this method of feeding is to produce an iron of regular composition for the steel furnaces. In this respect it is advantageous, but certain disadvantages are also clearly obvious:

> (i) When low-silicon iron is received from the blast-furnaces, the mixer does little work, and the banks are probably being cut by the thin slag
>
> (ii) When high-silicon iron is received, the oxidizing additions cannot be fully melted in the three-hourly periods available, so that the bath may be rendered inactive by the excessive amounts of material charged. This prevents proper slag removal, and any that is drained away may be high in iron. Reactions are eventually slowed down, so that feeding must stop to allow the bath to melt and clear
>
> (iii) With this method of feeding, the mixer can never work to full melting capacity, and at the same time give uniformity of iron, unless the charged metal is very consistent in composition, and the ingoing and outgoing quantities are also fairly uniform. The greater the variation of the incoming silicon analysis the less can be the actual melting capacity of a given mixer relative to its total melting possibilities.

To use a mixer fully, feeding must be done steadily, and as rapidly as the materials can be melted. These quantities are normal characteristics of the furnace and can, therefore, be fairly consistent. When this method is used, the swing in outgoing iron analysis will be almost an exact replica of the variations as charged, but on a lower mean silicon level. These variations cause difficulties in steel-furnace operation, unless they can be countered during the course of each charge. Since 1942 this has been done fairly exactly and easily by the slag-control methods adopted at that time.*

When this method of feeding was introduced, Mixer 1 was redesigned to bring it into line with Mixer 2, and sufficient coke-oven gas was mixed with blast-furnace gas to keep the mixers at maximum temperature. This increased the weight of cold material that could be melted to 3–3½ cwt./ton of iron charged (*see* Tables III and IV).

The scrap added to the mixer is normally light material from the plate mill, and which, owing to its bulk, may delay charging of the steel furnaces. This reduces the mixer phosphorus by dilution.

In considering the quantity of material that can be melted by the mixer, it seems that, if taken separately, the mixer has a definite capacity for melting slag-forming additions or scrap, but if both types of material are used, the total amount that can be melted is greater than that of either used individually. This seems to be due to the relative inactivity of the mixer bath, which only allows a certain amount of reaction to take place, and this is insufficient to cool the metal beneath to a temperature at which it gives an important amount of skull in the transfer ladle. This excess temperature can, when scrap is added, be used in dissolving this material, so that by judicious mixing and making additions at the correct time, an iron low in silicon and lower in phosphorus can be produced with just enough heat to enable it to be carried to the steel furnaces and poured in without important skulling loss.

Slag should be removed from the mixer as rapidly as possible, otherwise feeding will cause a bulky slag to foam over the doors when further additions are made, and also retard the rate of oxidation of the bath. Slag should, therefore, be removed frequently, and as it is exhausted, so as to make sure that only a thin layer is normally present on the metal. To ensure that iron is not lost, the slag is sampled whenever any is removed, and the iron content should be between 6·5 and 7·5%; it must not exceed 8·0%.

This type of practice proceeds more rapidly in a mixer with a bath 4 ft. 6 in. deep than in one with the more normal bath depth of 6 ft.–6 ft. 6 in.

The effect of changing mixer practice, mixer design, and iron composition is seen in Tables III and IV. The slag samples shown are the average of several hundreds, taken every few hours throughout the day, and average at least one for every pan of slag (14 tons) removed. The analysis of iron charged is that supplied by the blast-furnaces, and the iron out of the mixer is the average of the three-hourly samples taken throughout the year.

'R' FURNACE MIXER

This furnace was used, with its normal capacity of 300–350 tons, as a mixer to produce about 4000 tons of iron per week to a fixed analysis, aiming at 0·2–0·25% of silicon. This gave an iron with about 0·5% of manganese, but when the silicon was further reduced, the manganese fell to about 0·3%. The refined iron was poured at the pig-casting machine.

The production could have exceeded 4000 tons had more iron been available, but it would not have been possible to maintain the same precise degree of analytical control.

To produce this throughput and analysis regularly, a fixed schedule must be established, and it was decided to use a batch process instead of normal mixer practice in which iron is charged as received and drawn as required. The batch was based on an 8-hr. cycle, designed to give the maximum amount of physical work at the beginning of the shift, with refining taking place when the shift ended.

The cycle begins half an hour after the shift starts, when slag is removed (30 min.), and the furnace is tapped (30 min.), leaving 20–50 tons of metal in the hearth.

* A. Jackson: *J. Iron Steel Inst.*, 1944, No. I, pp. 49P–66P.

Table V

RESULTS OF MIXER FEEDING TESTS

	Mixer 1			Mixer 2		
	Tons	Cwt. ton		Tons	Cwt./ton	
Metal charged	3635			3809		
Scrap "	342			Nil		
Total "	3977			3809		
Limestone	198	0·99		Nil		
Burnt lime	Nil			13	0·07	
Oxides	198	0·99		Nil		
Slag made	320	1·61		30	0·16	
	In, %	Out, %	Removed, %	In, %	Out, %	Removed, %
Sulphur	0·094	0·075	19	0·086	0·052	40
Silicon	0·940	0·280	70	1·040	0·740	29
Manganese	1·030	0·480	53	1·060	0·930	12
Phosphorus	1·44	1·090	21	1·510	1·410	7
Av. temp., ° C.		1301			1347	
	Slag Analysis, %					
SiO_2	26·6			33·7		
Al_2O_3	2·11			4·59		
CaO	39·4			48·4		
MnO	8·95			2·27		
MgO	6·00			6·00		
P_2O_5	6·25			0·23		
Sulphur	0·165			0·285		
Total iron	6·8			2·1		

As soon as tapping is complete, the furnace is tilted towards the stage and fettled while still hot and sticky, and at top heat. The taphole is then closed while this dolomite is burning in. Eight to ten tons of oxides and 6–9 tons of limestone are added, and any further fettling required at a higher level of the bath is completed (30–40 min.). The oxides are heated at the maximum temperature of the furnace for 1½–2 hr., which further burns in the dolomite. The addition of metal begins 4 hr. after the start of the cycle, the several ladles being charged in rapid succession. A good reaction occurs at this point. The charging metal must be available as soon as it is needed; if it is not, the oxides melt, and very violent reactions occur when the metal is added. The process is therefore delayed by the need to add the iron very cautiously.

During the next 3 hr., chutes, launders, etc., may be cleaned and repaired, ready for the next tap. Oxides and limestone are also placed on the stands ready for the next charge, and other preparatory work is completed.

One-and-a-half to two hours after the metal is added, a sample is analysed for silicon and sulphur, the results being available in 30–40 min. More oxides and limestone are added if needed, but if the silicon is low, a further 50 tons of blast-furnace metal are charged.

When this has worked through, and as near the time schedule as possible, an immersion temperature is taken and the slag is removed. Gas supply is adjusted at this point to correct the metal temperature, which is very important and should not exceed 1380° C. If it is between 1380° and 1430° C., very rapid wear of ladles takes place, and their life is reduced to less than one-sixth of that normal for iron transfer. Without control, the temperature can rise as high as 1450° C. very quickly, which damages the furnace hearth, landers, ladles, and even pig-casting machine moulds.

Ladles used to transfer the iron from mixer to pig-casting machine are retained for this purpose to avoid contamination with blast-furnace slag and the danger that can result from breakouts, unless a careful control of the life of these ladles is maintained. The normal tap comprises three ladles, each of 60 tons, but at intervals it may be necessary to tap a fourth. A bath sample taken between the first and second ladle is regarded as the cast analysis.

The figures for the run from July to November, 1945, were as follows:

Make:
67,120 tons of refined iron

Consumption:

Molten metal	19·42	cwt./ton	of	refined	iron
Cold iron	0·40	,,	,,	,,	,,
Oxides	0·85	,,	,,	,,	,,
Ironstone (local)	0·44	,,	,,	,,	,,
Limestone	0·65	,,	,,	,,	,,
Skulls made	0·12	,,	,,	,,	,,
Slag made	1·59	,,	,,	,,	,,

Table VI

EFFECT OF SLAG VOLUME AND SULPHUR CONTENT OF IRON ON SULPHUR LOSS

Mixer Slag Made, cwt./ton	Sulphur in Iron at Blast-Furnaces															
	0·060–0·069%				0·070–0·079%				0·080–0·089%				0·090–0·099%			
	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
0·60–0·79	0·015	0·15	0·43	35%	0·017	0·21	0·49	45%	0·021	0·25	0·60	42%	...	...	...	...
0·80–0·99	0·013	0·15	0·29	52%	0·015	0·14	0·33	42%	0·019	0·27	0·42	66%	0·023	0·14	0·51	27%
1·00–1·19	0·008	0·15	0·15	100%	0·012	0·14	0·22	64%	0·017	0·15	0·31	48%	0·019	0·17	0·35	49%
1·20–1·39	...	...	...	...	0·015	0·15	0·23	65%	0·012	0·20	0·18	A	...	...	...	...
1·40–1·59	0·003	0·16	0·04	A	...	...	...	...	0·012	0·17	0·16	A	0·011	0·20	0·15	A
1·60–1·79	...	...	...	...	0·006	0·18	0·07	A	0·011	0·18	0·13	A	0·012	0·17	0·14	A

a = Average sulphur loss in transit and mixer
b = Average sulphur in mixer slag
c = Average sulphur content of slag, if all sulphur lost had remained therein
d = Percentage of sulphur lost by iron and retained in slag
A = sulphur in slag in excess of the quantity lost by the iron

The average analysis over the whole period of working was:

	P, %	Mn, %	Si, %	S, %	C, %
Metal in	1·47	0·99	1·01	0·073	3·45
Metal out	1·29	0·55	0·26	0·061	3·15

Average slag iron: 8·4 %

Metallurgical Relationships

During the above run of this mixer, the information collected was examined to see if any relationships could be found between various factors, but no significant results were found. Those considered were:

(i) Iron temperature at 'slag off' against tons of silicon eliminated and percentage of slag iron
(ii) Iron in slag at 'slag off' against tons of metal refined per hour, percentage of silicon eliminated, and silicon or sulphur content at 'slag off' or tapping
(iii) Amount of scale and limestone charged against weight of silicon eliminated.

No relationship was shown between these in ordinary mixer practice, but as this batch process achieved greater uniformity, it was considered worthwhile to examine the information available.

The amount of silicon eliminated, once the correct amounts of oxide and limestone have been added, appears to depend mainly upon the preliminary reaction achieved when molten iron is poured upon heated limestone and oxides, and following this, to a limited extent, upon the time that this reaction is allowed to continue undisturbed. After a short time, the mixer becomes quiescent, and then the rate of reaction is apparently very slow.

The rate of production, when the iron produced is to have a fixed silicon content, appears to depend upon the rate at which the oxides and limestone are heated to a high temperature, and the time from 'last tap' to charging the metal; *i.e.*, the shorter this is, consistent with the oxides being well heated, the greater the production of iron as shown by this trial.

EFFECT OF RATE OF FEEDING ON DESULPHURIZATION IN MIXERS

In November, 1948, a direct experiment, lasting one week, was made to find the effect of the rate of feeding the mixer on steelmaking practice and costs.

One mixer was fed in the normal manner, and the other was covered with a layer of burnt lime only. Only 12·6 tons of lime were added during the week, but this was enough to maintain a thick lumpy slag that was difficult to remove and adhered to the bank sufficiently to prevent normal fettling. After a week the mixer was cleaned out and fettled, a process requiring 36 hr., before it was back to normal operation.

The results of the experiment are given in Table V.

The mixers were filled at random with iron from the blast-furnaces, the difference in ingoing analysis shown arising essentially from variations in iron quality. The average iron charged into Mixer 1 contained 0·98% of Si, the difference of 0·04 being due to allowance for the composition of the added scrap. The remaining figures are similarly modified.

Summary

Complete stoppage of feeding doubled the amount of sulphur removal (to 40%), with less than a quarter of the manganese loss. The mixer without feed formed a very thick, lumpy slag, and needed a heavy fettle at the end of a week.

The comparative samples 'in' and 'out' are taken at the blast-furnaces and on leaving the mixer, respectively. The sulphur removal, therefore, includes that taking place during transfer to the steelworks.

EFFECT ON STEEL FURNACES OF RATE OF FEEDING MIXERS

The object of this experiment was to show:

(i) The difference in rate of sulphur removal in the mixer, with and without feeding
(ii) The value of the low-sulphur iron in reducing sulphur delays in the steel furnaces
(iii) The extra steelmaking costs involved in using higher-silicon–lower-sulphur mixer iron.

The effect on the steel furnaces was as follows:

	Low-Sulphur Mixer Iron	Normal Mixer Iron
No. of charges	20 (6000 tons ingots)	16 (4800 tons ingots)
Charge (silicon), %	0·74	0·28
Tap (manganese), %	0·20	0·16
Pit (sulphur), %	0·041	0·047
Time lost per charge for sulphur, min.	Nil	29
Time lost per charge for silicon, min.	206	Nil
Tons/hr.	10·66	12·02

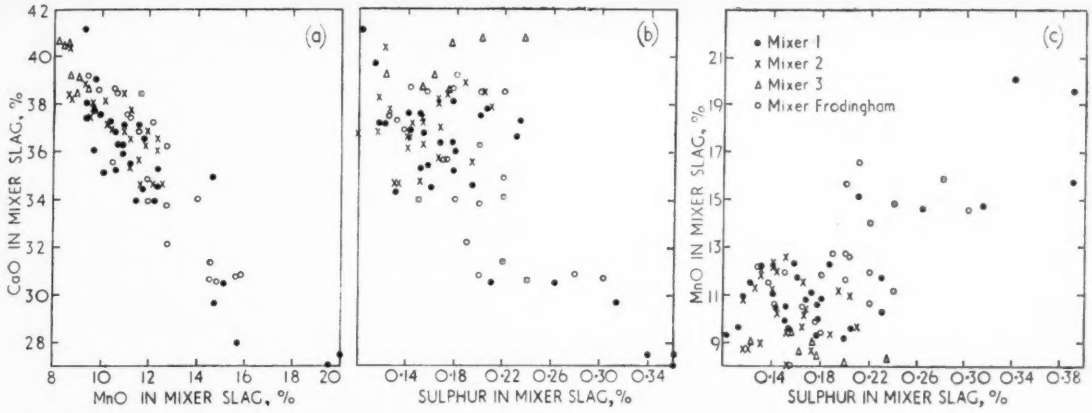

Fig. 5—Relationship in mixer slags between : (*a*) MnO and CaO; (*b*) CaO and sulphur; (*c*) MnO and sulphur

The aim in all casts was to tap on 0·05% of sulphur. The furnaces charged with the low-sulphur iron were all below specification when the phosphorus was sufficiently low. This would be influenced by the added slag bulk produced in these charges.

The steel production loss resulting from ceasing to feed the mixer shown by this 7-day test is about 10%.

LOSS OF SULPHUR IN TRANSIT AND MIXER

The half-yearly average figures for iron and slag analyses were examined to find how much of the sulphur lost, from the time when the iron left the blast-furnaces to when it was charged into the steel furnaces, was in the mixer slag, and if there was any direct relationship between these two figures.

It was realized that part of the sulphur may have been removed by flotation as MnS in the ladle during transit, but, unless oxidation had taken place, it might be expected that the sulphur contained in the ladle scum would be poured into the mixer with the iron, and so pass the sulphur back to the mixer slag.

Effect of Manganese and Sulphur Content of Iron on Sulphur Loss

The effect of the manganese content of the iron leaving the blast-furnace on the sulphur loss in transit and in the mixer is shown in the following half-yearly figures. The figures in brackets show the numbers of samples in the groups :

Manganese in Iron at Blast-Furnaces, %	Sulphur in Iron at Blast-Furnaces, %			
	0·060–0·069	0·070–0·079	0·080–0·089	0·090–0·099
0·9–0·99	...	0·010 (2)	...	0·021 (4)
1·0–1·09	0·009 (5)	0·012 (12)	0·013 (11)	0·022 (4)
1·1–1·19	0·012 (3)	0·014 (6)	0·017 (13)	...
1·2–1·29	...	0·015 (5)	0·019 (4)	...

These figures show that the sulphur loss increases with:

(i) Increasing manganese in the iron with a constant sulphur content

(ii) Increasing sulphur in iron with a constant manganese content.

The results are of the order to be expected from existing published knowledge. When, however, efforts are made to identify the sulphur lost with that found in the mixer slag, complications arise.

Effect of Slag Volume and Sulphur Content of Iron on Sulphur Loss

The figures available are given in Table VI, which shows that:

(i) With a given slag volume, the amount of sulphur lost in transit and in the mixer increases with increasing sulphur in the iron at the blast-furnace

(ii) With a given sulphur content in the iron, the sulphur loss decreases with increasing slag volume

(iii) With low slag volumes, less than half the sulphur lost is found in the slag

(iv) With high slag volumes, the slag has acquired large quantities of sulphur from other sources.

It is difficult to explain these deductions fully. Heavy feeding, shown here by high slag volume, reduces the percentage of sulphur eliminated in the mixer, but the reasons are difficult to find.

No explanation is apparent to show why, with small slag volumes in the mixer, sulphur is lost, although large volumes of slag indicate the absorption of important quantities of sulphur from sources other than the iron.

The average sulphur content of the mixer slags shown is 0·17%. The variations are rather wide, but the figures show that the slag will absorb this percentage of sulphur either from the metal or other sources. If rates of feeding are low, the slag may be fed with manganese sulphide floating from the iron, which keeps it saturated, any excess being oxidized and so lost. Heavy feeding prevents sulphur passing from metal to the slag, which then probably absorbs sulphur from the gases.

Slag Composition

An examination of slag analysis for prospective relationships shows the following to be interesting:

(i) Figure 5*a* shows a good inverse relationship over a wide range between the MnO and CaO contents of mixer slags

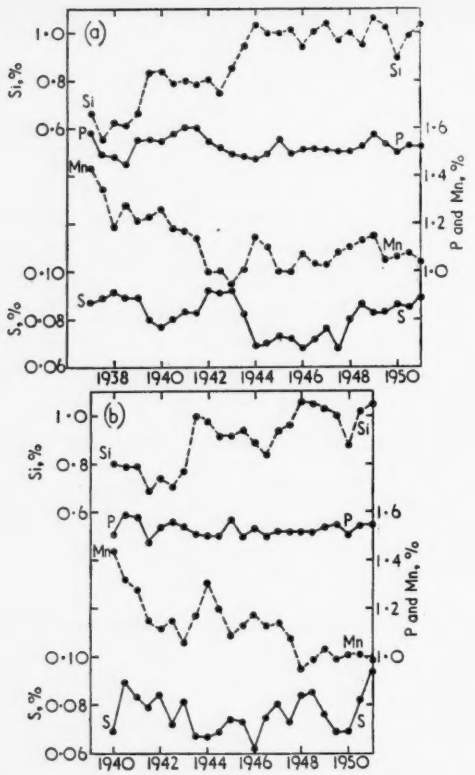

Fig. 6—Average yearly analysis of metal charged to (*a*) Appleby mixers; (*b*) Frodingham mixers

(ii) Figure 5*b* shows little relationship between lime and sulphur in the slags, although the low-lime end of the graph shows high-sulphur slags

(iii) Figure 5*c* shows some indication of increasing sulphur, with increasing MnO in the slags.

The slags containing over 0·26% of sulphur were made when the mixers were using low-silicon, higher-manganese iron, while making small slag volumes.

When the mixers were worked with less heat input and smaller slag volumes than those shown in the paper, the ratio between MnO and CaO in the slag was pronounced, and those between MnO and sulphur, and between CaO and sulphur, were quite definite. As the heat input has been forced to higher levels, the slag has become increasingly hot and limey, and the ratio between MnO, CaO, and sulphur has become indefinite. The effect of this increasing tempo is also evident from the important amounts of phosphoric acid now present in mixer slags.

A general examination of the slag analyses given in this paper does not show any other significant ratio.

RESULTS OF MIXER OPERATION

A series of results of mixer operation during the last 15 years is shown in Tables III and IV.

There appear to be enough figures to allow certain ratios to be deduced, with respect to variations in composition of the ingoing iron, but this is not the case.

Variation in Blast-Furnace Iron

Any attempt to plot the commonly accepted related variables in blast-furnace iron, such as silicon against sulphur or manganese, or manganese against sulphur, will fail to show any important relationship.

The reason for this lack of correlation can be seen in Fig. 6*a*, which shows the average yearly analysis of iron charged to Appleby melting shop from 1937 to 1951 inclusive. The other mixers (*see* Fig. 6*b*) conform closely. They show:

(i) Relative stability of the phosphorus content of the iron

(ii) A steady fall in manganese content, due largely to reduced returns of mixer slag to the blast-furnaces. This practice ceased entirely in 1942, as the metallic content of the slag was considered to be too low for economical smelting

(iii) Steelworks difficulties caused by high sulphur in the iron in 1942/43 made it necessary, as Company policy, to raise the silicon and so reduce sulphur

(iv) The sulphur content did not cause undue difficulties in the steelworks from 1937 to 1939, but the increased silicon that coincided in 1939 with the commencement of the new blast-furnace plant made sulphur removal a greater problem to the melting shop, despite the introduction of a second mixer

(v) A steady upward drift of sulphur shows in the latter years of the diagram.

Figures 7*a* and *b* show the iron analyses expressed as silicon below 0·7%, 0·9%, and 1·3%, and sulphur below 0·07%, 0·09%, and 0·12%, in the iron supplied to Appleby mixers.

It will now be clear why errors can arise: *e.g.*, plotting the whole series will show manganese to increase with decreasing silicon, or that no relationship exists between silicon or manganese and sulphur. The fallacies obviously arise from fundamental variations in iron analysis over the years.

If these variables in blast-furnace iron composition are to be studied, a short period, with a minimum of variables, should be plotted, but here again a purely statistical approach, without knowledge of the process, can be completely misleading; *e.g.*, mixer slag was recently added to four blast-furnaces in sufficient quantity to give an average content of 1·35% of manganese. None was added to the remainder, which, therefore, produced 0·98%.

In Figs. 8*a* and *b*, the full line gives a reasonable representation of the trend in relationship between manganese and sulphur in the iron leaving the blast-furnace.

Comparison of the two curves shows that in furnaces without a manganese addition, a content of 1·19% will coincide with 0·07% of sulphur, but when manganese is added, 1·46% is necessary to give the same sulphur content. This means that blast-furnace conditions that give a high yield of 1·19% of manganese against an average of 1·0% are especially favourable to sulphur removal. The iron is hot and above average in silicon content, whereas in the furnaces in which extra manganese-bearing materials are added, 1·46% of manganese is little above the average operating conditions, and does not represent a yield above normal. The iron will not be hotter or higher in silicon than average.

Information shown previously, and based on short-term trials, shows that the effect of increasing

manganese in blast-furnace iron from 1·0 to 1·35% coincides with the production of lower sulphur, with the same silicon content, a marked advantage to the open-hearth process.

ESTIMATION OF OPERATIONAL EFFICIENCY OF A MIXER

In any process, it is desirable to have some figure that gives an immediate indication of the efficiency of the process. In a mixer working to give constant iron analysis, frequent samples estimated for silicon will give the requisite rapid indication. If, however, the furnace is being used to remove the maximum amount of silicon content of the iron leaving, the weight of iron charged must also be known.

The amount of refining that a mixer can do depends essentially upon the amount of oxidizing and slag-forming materials that can be melted without reducing the metal temperature to a point where excessive ladle skull is produced during transfer to the steel furnaces.

Practice shows that the quantity of oxidizing materials that can be melted increases appreciably with increased throughput of iron. This is probably due partly to the increased agitation of metal and slag during charging and discharging and partly to the increased quantity of silicon available for removal, so that the furnace does not arrive at the point where it is increasingly difficult to remove the last few points of silicon.

Under normal operating conditions, the most useful criterion of operating efficiency is given by an indication of the tons of silicon removed in unit time. The following figures are achieved on Appleby mixers on a day-to-day basis, without undue damage to the banks and linings, and are therefore used as a basis for daily standards (average for 1951 on two mixers):

Weekly Output Rate, tons	Silicon Removed Tons	%	No. of Weeks
6000	40·0	0·67	5
5000	35·5	0·71	34
4000	31·0	0·78	49
3000	26·0	0·87	10

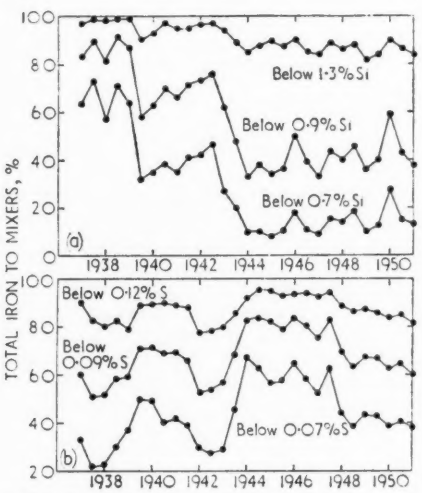

Fig. 7—Distribution of (*a*) silicon, (*b*) sulphur contents of iron supplied to Appleby mixers (half-yearly averages)

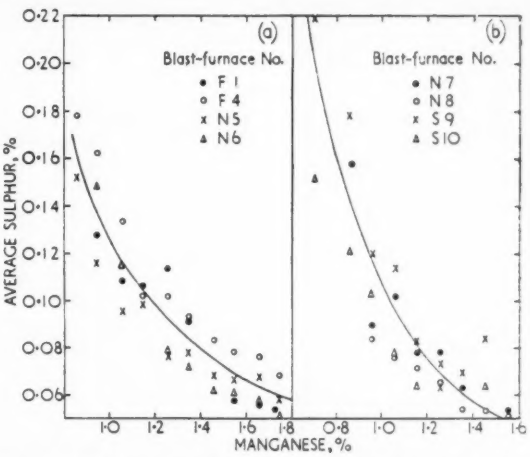

Fig. 8—Sulphur/manganese relationship in iron leaving the blast-furnaces: (*a*) With manganese slag added: (*b*) without manganese slag. (Based on daily averages, August–November, 1951)

In practice, standard curves are made from these figures and used as a daily control, investigation following any marked drop in the amount of silicon elimination that should be achieved.

For a given mixer, curves can be drawn to show the analysis of the 'metal out' in relation to the quantity and analysis of that charged. The following tabulation on this basis shows the variation in mixer throughput that would occur if a constant outgoing silicon content in the iron were maintained, with the ingoing analysis variations shown.

Silicon in Iron Charged, %	Mixer Capacity, tons/week Outgoing Silicon, 0·2%	Outgoing Silicon, 0·3%
1·2	...	2200
1·1	2200	4000
1·0	4000	5500
0·9	5500	6800
0·8	6800	7800

These figures show that increasing the silicon in the iron charged from 0·8 to 1·1% reduces the effectiveness of two mixers to that of one, if an average of 0·3% of silicon is to be maintained in the outgoing metal.

Further study of figures obtained in this way will show that, in a mixer working at a given throughput, any increment of silicon in the iron charged is transmitted directly to the 'iron out' without reduction; *i.e.*, the amplitude of variation in iron analysis as received is repeated exactly, but at a lower silicon level, in the metal produced.

In practice, there is a strong tendency for the operative to reduce the rate of feeding as the silicon in the outgoing iron falls. This may be necessary to some extent, because the low-silicon metal needs to be at a higher temperature to avoid ladle skulling, but it must not be overdone.

EFFECT OF MIXERS ON STEEL FURNACE PRODUCTION

The capital cost of a modern mixer is almost the same as that of a large tilting furnace, which some-

times raises the question of whether all the furnaces should make steel using iron direct from the blast-furnaces, or whether one or more should be used as mixers, to feed the remaining steel furnaces.

Many factors must be considered in answering this question, the foremost being iron quality. The answer given is based on the iron analyses already shown, *i.e.*, Lincolnshire basic, which is rich in phosphorus and as variable in day-to-day analysis as the ores from which it is made.

The calculations consider three, four, and five furnaces, in which either all use direct metal or one is a mixer and the remainder are steel furnaces.

The outgoing mixer analyses increase in silicon with the increasing throughput from added furnaces, in accordance with the tabulation shown previously. The effect on the steel output of the silicon content in the mixer iron charged to the steel furnaces is well known from many investigations. The productions achieved when using direct metal are derived from various occasions, accidental or by design, when mixers were not working.

Typical figures show production gains when all furnaces use direct metal, compared with using one as a mixer, to be:

3	Furnaces	9%
4	,,	3%
5	,,	Nil

Summary

There is a gain in production with three and four furnaces if they are all used on direct metal. With five furnaces, the production will be the same as for four furnaces and one mixer. Using direct metal (25% scrap) gives great variability in the product, and increases mill defectives.

A mixer is much cheaper to run than a steel furnace, and so ingot costs are a little lower. Experience shows that when the mixer is 'off for repairs' in a given shop, the ingot cost changes very little, but production drops to about 75% of normal. Direct metal operation causes much irregularity in production, owing to variation in iron quality, extra fettling, etc., and so greatly inconveniences the mills. All our experience shows one mixer to three operating steel furnaces to give the best results.

If the iron is very variable, and a pig-casting machine is used to balance iron make against steelplant usage, a large steelworks could give many reasons for installing a large inactive mixer before the smaller active mixers on the steelplant.

OXYGEN LANCING

Oxygen lancing of mixers has been attempted, but the results are far from satisfactory. Primarily, the cost is relatively high owing to loss of yield and the cost of oxygen and pipe. Information obtained by blowing oxygen into iron transfer ladles has given figures that indicate these costs to be higher than those of mixer treatment in the Appleby melting shop.

The blowing trials showed the following mechanical difficulties:

(i) Flexible pipes on the stage impeded the passage of the charging machines

(ii) The hole into which the hot-metal ladle is lowered when tapping the mixer is impossible as a platform for those operating the lances

(iii) These difficulties made it necessary to apply the oxygen lances from the pit side, and, although this overcame the troubles, it allowed only a limited operating space, which made handling of long lances, with flexible tubes attached, a hazardous occupation

(iv) Charging, discharging, feeding, slagging, and fettling all reduce the time during which oxygen can be blown. These operations often take place in mixers dealing with 700–900 tons/day, the average weight of the outgoing ladles being about 26 tons

(v) Initial blowing trials showed that as little as 10,000–15,000 cu. ft. of oxygen per hour produced much foaming, which could only be minimized by lowering the metal level and covering it with a specially heavy feed. This enabled oxygen to be blown, but materially reduced the normal activity of the slag reactions. This apparently neutralized the effect of the application of oxygen on the total work done in the mixer

(vi) Even if foaming could be eliminated, the bath cannot be kept at sill level, as in the O.H. furnace, so that blowing may sometimes have to take place at a depth of 4 ft. or more. This requires a long pipe, which is exposed to heat and so bends, with the result that the oxygen pressure, coupled with the lumpy slag, causes the jet to spurt from the slag in all directions, spraying the banks, the linings, and even the roof with a mixture of slag and oxidized metal

(vii) Large volumes of fume are formed; the experiments were insufficient to give any indication of its effect on brickwork and regenerators

(viii) Oxygen blowing increases the metal temperature, and seems to coincide with heavy cutting of the banks and hearth, although this is not considered to be a conclusive result from these few trials.

Summary

Trials of oxygen lancing in the mixers were made, and discontinued because of the difficulties of satisfactory application to the metal bath, the known cost increases due to materials and yield loss, and the insufficiency of molten iron arising from the present national shortage of steelmaking materials.

Acknowledgments

This paper contains a summary of information, from reports and other sources, collected by the author over many years. The work involved was done by the staffs of the Melting Shops, Laboratories, Engineering Research Department, and many others, and certain sections were instigated by the late Dr. T. Swinden and Mr. F. Saniter of The United Steel Companies' Central Research Department. The author wishes to record that this report is the result of the labours of many people, and to thank Lt.-Cdr. G. W. Wells, General Manager of Appleby-Frodingham Steel Company, for encouraging its publication.

IRON AND STEELWORKS ENGINEERING

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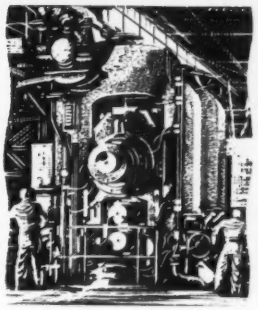

A New Hot Mill For Strips Up To 24 in. Wide

By M. Langen, A.M.I.Mech.E.

SYNOPSIS

The arrangement, design, and performance of a new continuous hot mill for strips up to 24 in. wide are described in detail.

MEDIUM-WIDE strips, say, up to 24 in., are usually hot-rolled in semi-continuous mills with either two or three roughing stands, arranged in line, feeding a 3- or 4-stand continuous finishing train or a single 3-high or 2-high reversing roughing stand in front of a 4- or 5-stand continuous finishing train.

The Société Anonyme des Laminoirs, Hauts-Fourneaux, Forges, Fonderies et Usines de la Providence, at Rehon, in the east of France, has for a long time produced hot-rolled strips $\frac{3}{4}$–16 in. wide on (i) a 12-in. mill comprising a 2-stand roughing train with automatic repeaters inside and between the stands, a 4-stand intermediate looping train, and a 5-stand continuous finishing train; and (ii) a 20-in. mill with a continuous roughing train comprising four 2-high stands, one horizontal edging stand for the first pass and one vertical edging stand for the last pass, and a finishing train with three double 2-high mill stands, equipped with roller tables as well as repeaters.

Although the 20-in. mill produced a good strip with satisfactory efficiency, it was decided in 1948 to replace this installation by a plant capable of producing strips up to 24 in. wide with a maximum output of 100 tons/hr.

Apart from this high output the installation had to be suitable for rolling low- and high-carbon as well as low-alloy steel strips 4–24 in. wide and 0·04–0·25 in. thick, with a coil weight of 285 lb./in. of width.

In addition, every consideration had to be given to guarantee the highest possible surface finish of the products and extremely close tolerances for both width and thickness.

The only solution for these requirements was a continuous mill, and in view of the ever-increasing demand for hot-rolled medium-wide strip of high quality, the arrangement, design, and performance of this fully continuous hot mill for strips up to 24 in. wide, which has recently been put into production, are here described in some detail.

GENERAL LAYOUT OF PLANT

The arrangement finally adopted is shown in Fig. 1; basically it resembles the layout of a modern wide-strip mill.

The buildings comprise the furnace and slab storage bay with a width of 95 ft. and three longitudinal bays, one 52 ft. wide for main drives and electrical equipment, one 52 ft. wide for the hot mill, and one 115 ft. wide for coil storage; the latter two bays are 780 ft. long.

This length of the mill building was determined by the fact that the slab storage bay had to match up with the existing bay which houses the finishing end of the blooming and heavy structural mills, whereas the coiler bay had to be connected with the existing storage bay for the 12-in. strip mill to facilitate mixed shipments.

The arrangement of the reheating furnaces and roughing mill was influenced by the demand to utilize, for the normal rolling programme, a slab thickness of only 3 in. which, in accordance with the desired coil weight of 285 lb./in. of width, fixed the slab length at 28 ft. 6 in.

This comparatively small slab thickness for a continuous strip mill was determined by the capacity of the existing blooming mill and structural mills and the necessity to fire the reheating furnaces normally by blast-furnace gas only. Furthermore, it was thought that a 3-in. slab would facilitate the rolling of small-gauge strip with very close tolerances and the highest surface quality.

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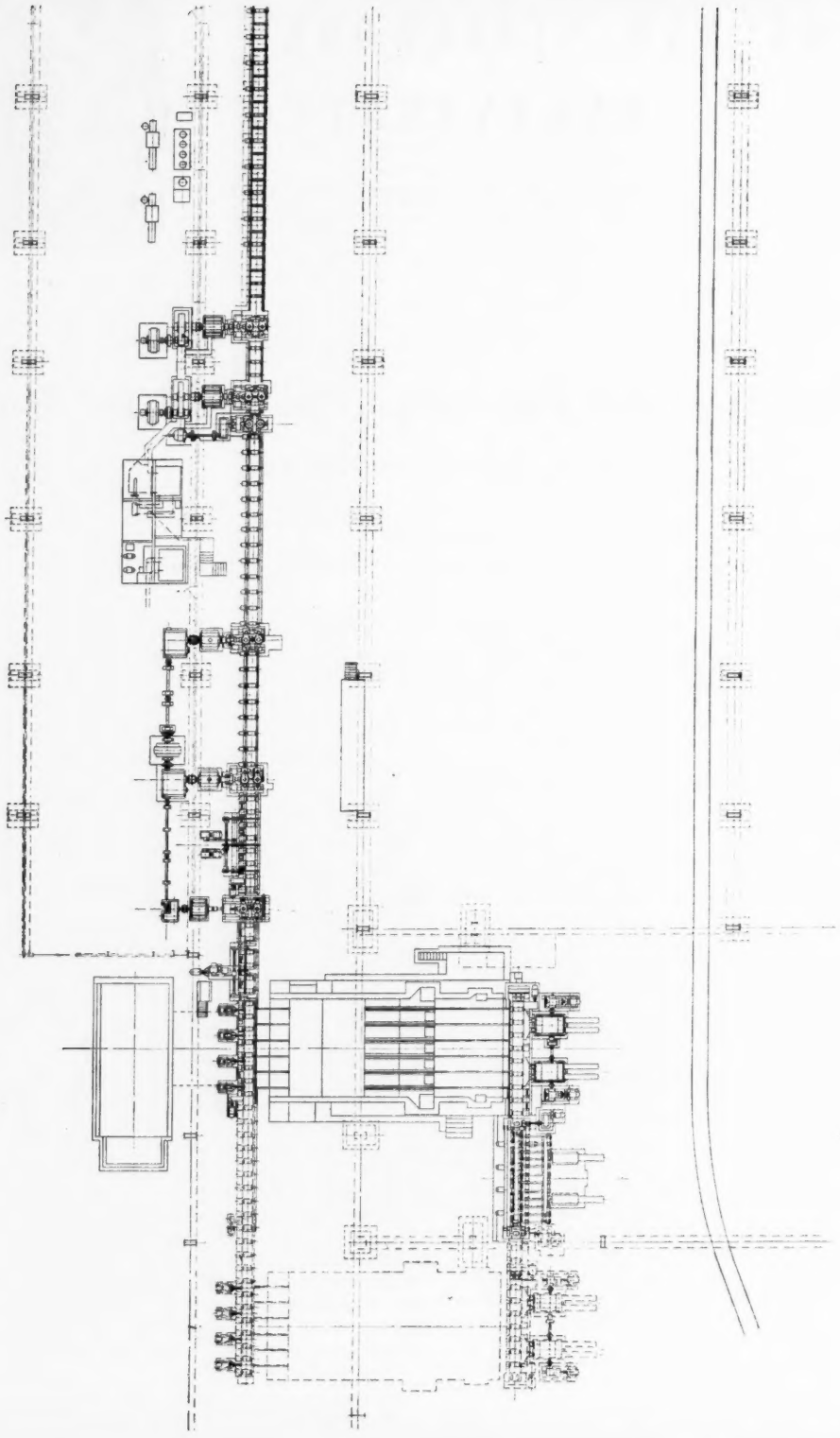

Fig. 1—Layout of strip mill (*continued below*)

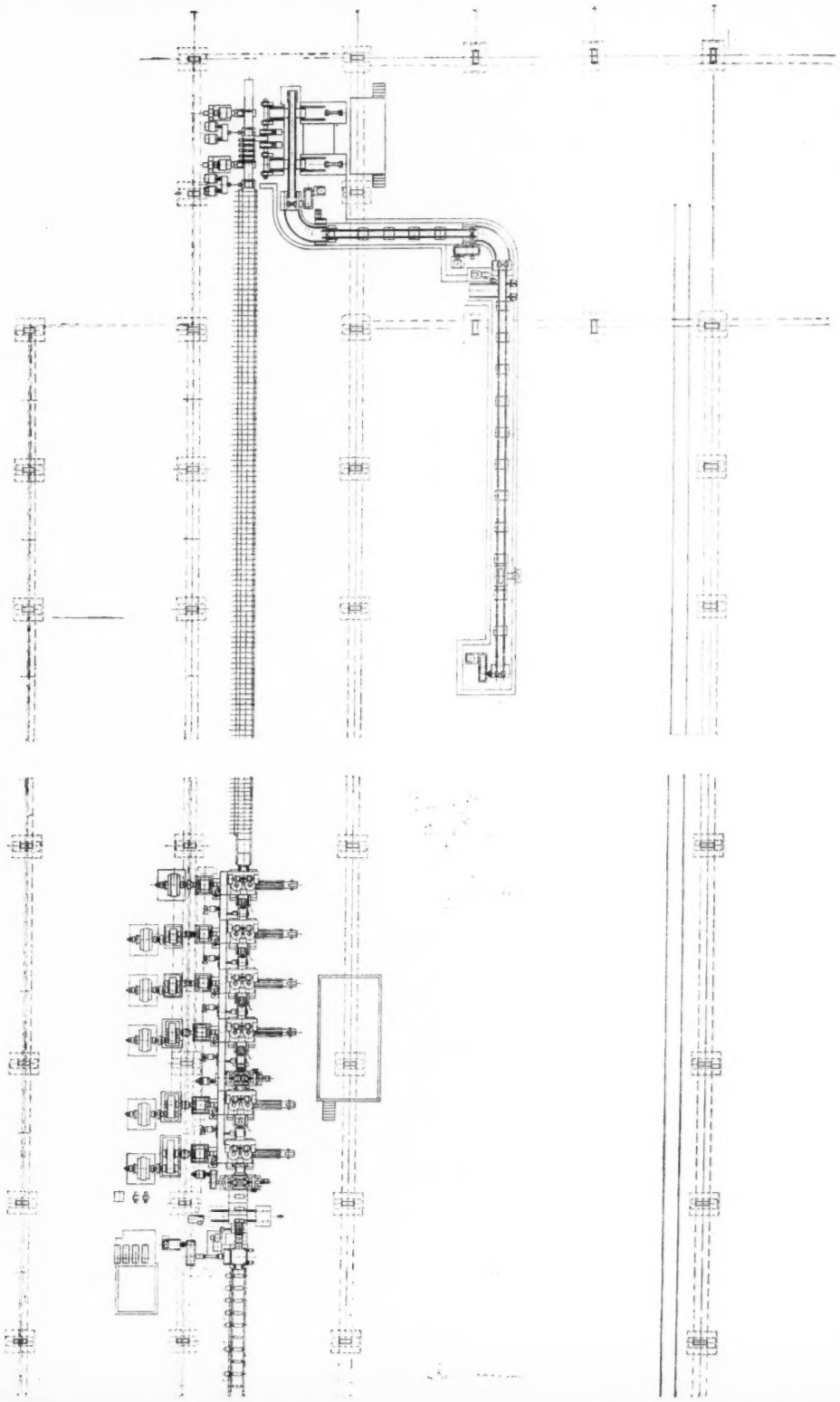

Fig. 1—Layout of strip mill (*continued from above*)

All slabs coming from either the blooming mill or the heavy structural mill are piled after shearing and are stored in the slab yard of adequate floor area. The slab yard is served by two overhead claw cranes and a separate portal crane with two magnets to facilitate spreading out, turning, and piling of slabs during surface conditioning by chipping or flame scarfing.

Piles of slabs are placed into a depiler in front of which is a charging grill and a pusher which allow more latitude in the delivery sequence of the overhead claw crane. The depiler transfers single slabs to the roller tables leading to the front of the two furnaces into which they can be charged in either single or double rows by suitably designed motor-driven pushers.

The rolling mill proper comprises, in general:

Roughing train with four 2-high mill stands, one horizontal 2-high edging mill for the first pass, and one vertical edging mill in front of stand 3

Finishing mill with six 4-high mill stands, and two vertical edging mills—one in front of stand 1 and one at the back of stand 2

Two down-coilers with discharge equipment and coil conveyors.

DETAILS OF ARRANGEMENT AND DESIGN

In the following description, detailed information is confined to items which are thought to be of interest.

Reheating Furnace

At present only one of the two furnaces is installed, with an output of 60 tons/hr. This furnace, of the Rust type as shown in Fig. 2, is normally heated by blast-furnace gas only, the gas having a calorific value of 100 B.Th.U./cu. ft. The hearth width is 30 ft. and the length from charging to discharging door is 70 ft.

There are three zones, the main heating zone being top- and bottom-fired. The horizontal furnace hearth consists of six water-cooled tubes leading from the charging door to the soaking zone and of refractory puddled chromide clay in the soaking zone. The arches are of the flat Detrick system. All burners are of the induction type, those of the heating and soaking zones being provided for a mixed gas/oil feed to increase the furnace capacity if necessary. The air required for combustion is heated to 700° C. in a refractory recuperator situated underneath the furnace and is then drawn by a blower to the burners for the heating and soaking zones, the burners for the preheating zone being fed with cold air from a separate blower. The hot-air temperature is thermostatically controlled.

The blast-furnace gas is preheated to 400° C. in a metallic recuperator heated by all products of combustion, this recuperator being protected against a possible increase of temperature by an automatic damping device which admits cold air into the flue.

Heat adjustment for various outputs is carried out automatically by thermostatic control devices in all three zones.

Automatic adjustment is provided for the fuel/air ratio as well as for the internal pressure.

Roughing Train

The horizontal edging stand and roughing stands 1 and 2 are driven by a common A.C. motor of 1850 h.p., the distance between these stands being sufficient for a free run-out of the slabs.

Roughing stands 3 and 4 are individually driven by 1850-h.p. A.C. motors and work in tandem.

The horizontal edging mill is designed for rolls 27½ in. dia. and a barrel length of 35½ in. These rolls are provided with five grooves of various depths which, together with a centre adjustment of up to 37 in., cover the whole range of slab widths.

Horizontal rolls are used for the first edging pass because squeezing the slab on edge assures a free fall of scale and a horizontal mill of this size is simpler and more reliable for the heavy duties to be performed.

The edging mill had to be equipped with a device for putting on edge the slabs coming from the furnace, and a manipulator at the back of the stand for turning the slabs flat and shifting them laterally to the desired position in front of roughing stand 1. This shifting of the slabs into any position is required for the off-centre rolling of strips with a width of 10 in. and below, which avoids too frequent roll changes and, above all, increases the total life of the rolls.

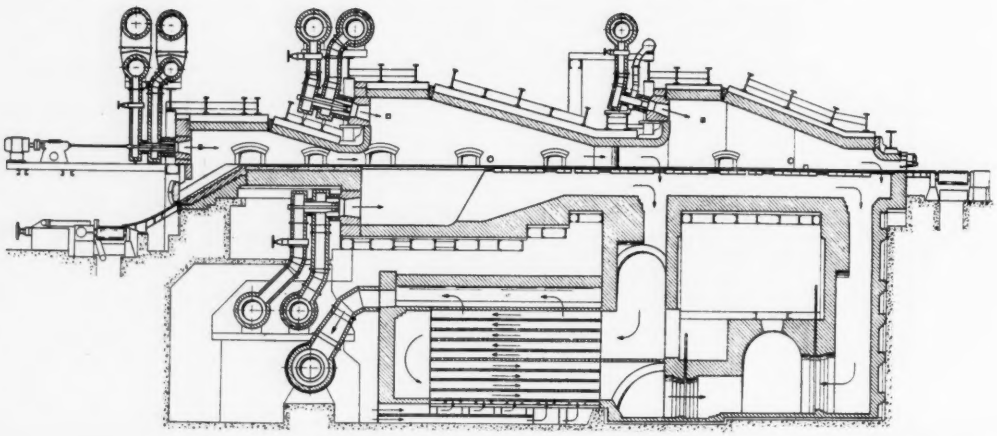

Fig. 2—Section of slab-reheating furnace

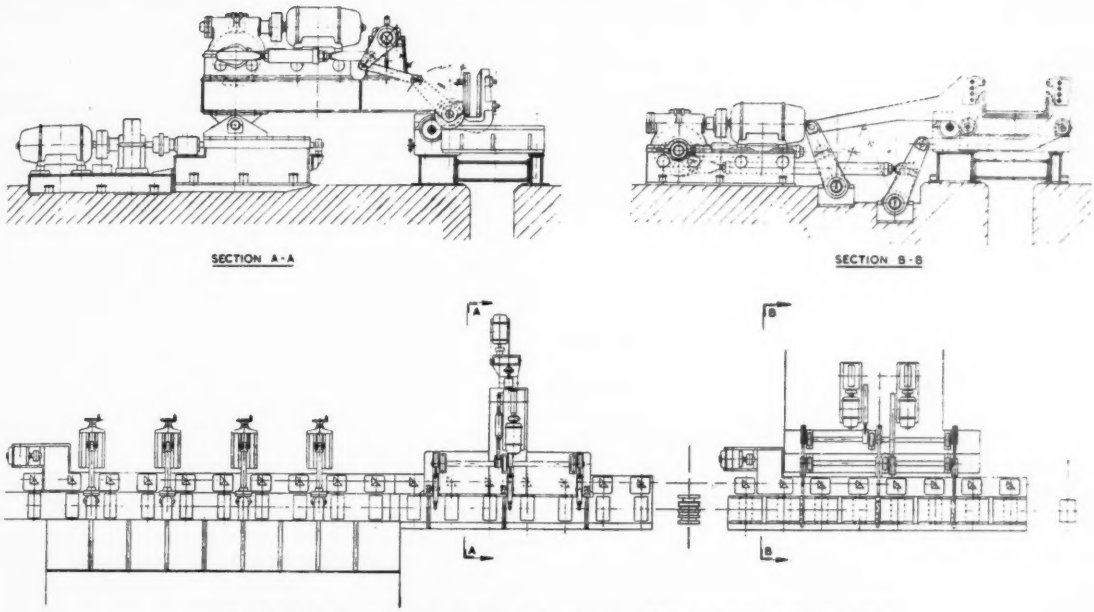

Fig. 3—Manipulators in front and at back of horizontal edging mill

These manipulators (shown in Fig. 3) are designed for quick operation to prevent any appreciable loss of slab temperature.

Under normal conditions the manipulator in front of the edging mill does not have to move laterally since the spring-loaded stops at the discharging side of the furnace are adjustable so as to arrest the slab in such a position to bring it in line with the appropriate edging groove after being put on edge.

The rolling speeds in the roughing mills are:

Horizontal edging mill (average): 200 ft./min.
Roughing stands 1 and 2: 300 ft./min.
Roughing stand 3: 280 ft./min.
Roughing stand 4: 400 ft./min.

As already mentioned, the last two roughing stands work in tandem. This reduces loss of temperature and avoids secondary scale in front of the last roughing stand; an additional advantage was that the mill bay could be reduced by approximately 105 ft.

The desired reduction in the tandem stands can be easily obtained by roll adjustment only which has to keep the strip having a maximum thickness of 1 in. just slack between the stands to avoid its width being affected by tension.

All the roughing stands are of standard design with rolls 20½ in. dia. and a barrel length of 29½ in. The chocks are fitted with synthetic resin bearings and the

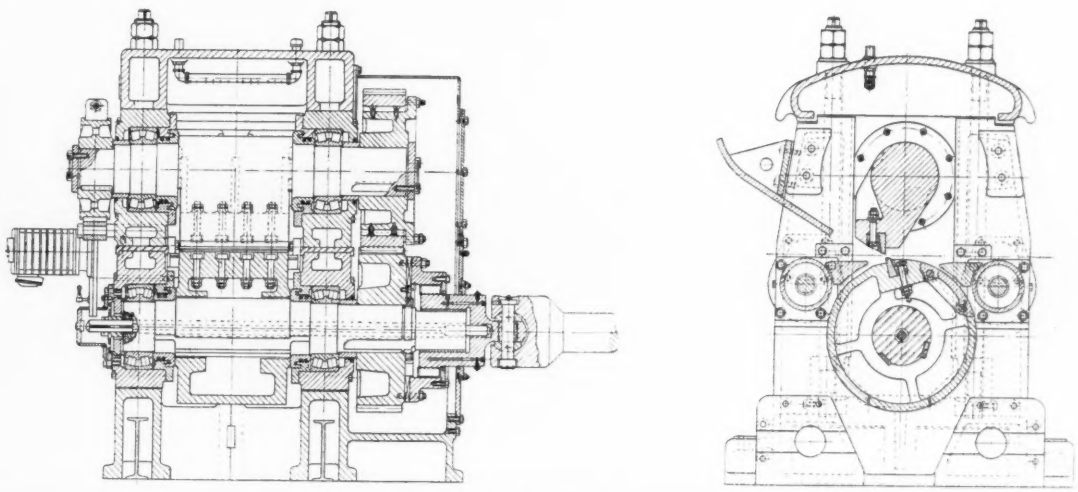

Fig. 4—Rotary shear

screwdown mechanism is handwheel operated. In spite of the comparatively small size of the stand the top roll is oil-hydraulically balanced to save time when roll changing.

The vertical edging mill in front of roughing stand 3 is of the overhung design, with 25½-in. dia. rolls. It is driven by a separate D.C. motor through a ratchet coupling which allows roll-speed synchronization. When rolling off-centre the unit can be shifted electrically to the desired position.

Finishing Mill

The run-out or delay table between the roughing mill and the finishing mill is 174 ft. long. At 140 ft. from the last roughing stand a rotary shear is installed for cropping, dividing, and emergency cutting.

The shear (Fig. 4) has a maximum shearing capacity of 24 in. × 1 in. and is driven by a variable-speed start-and-stop motor. To ensure a perfect cut the relative position of the blades can be accurately adjusted by shifting laterally the gear wheel driving the top cutter shaft. Since these gears have single helical teeth this shifting results in an individual small radial movement of the top blade.

A preloaded torsion bar, in conjunction with a special coupling, eliminates shock loads on the main drive and motor when the strip, to be cut in emergency, has a higher speed than that of the blades.

A tilting table behind the rotary shear can be lowered electrically for the crop ends to slide down a chute into one of two bins.

The finishing mill comprises six 4-high mill stands with rolls of 14¼ in. and 28½ in. × 27¾ in. The two vertical edging mills are situated in front of stand 1 and at the back of stand 2, the latter being used for heavy gauges only.

The mill stands are of standard design, *i.e.*, two-motor screwdown gear, oil-hydraulic roll balance, and sledge-type roll-changing gear. Both work and back-up rolls run in roller bearings. The pinions for the first three stands have centres of 14·86 in. and those for the last three stands 13·78 in. Each of the six stands is driven by a 2000-h.p. motor at 425–850 r.p.m. The first five stands are driven through gear reduction units whereas the last stand is direct-driven. The motor speeds and the ratio in the gear units allow the following rolling speeds:

Stand No.	Rolling Speed, ft./min.
1	234–468
2	410–820
3	695–1390
4	1020–2040
5	1365–2730
6	1570–3140

The edging mills are of similar design to the edger in front of rougher 3, the roll diameter being 20 in.

Figure 5 shows the table, exit and entry guides, and the loop lifter between the stands. The guides are arranged on carriers which can be easily drawn out of the stands for roll changing and can also be shifted sideways into any desired position for off-centre rolling. All these operations are carried out manually. The loop lifters are automatically controlled by constant-torque motors.

Coilers

Two horizontal down-coilers are provided, the first

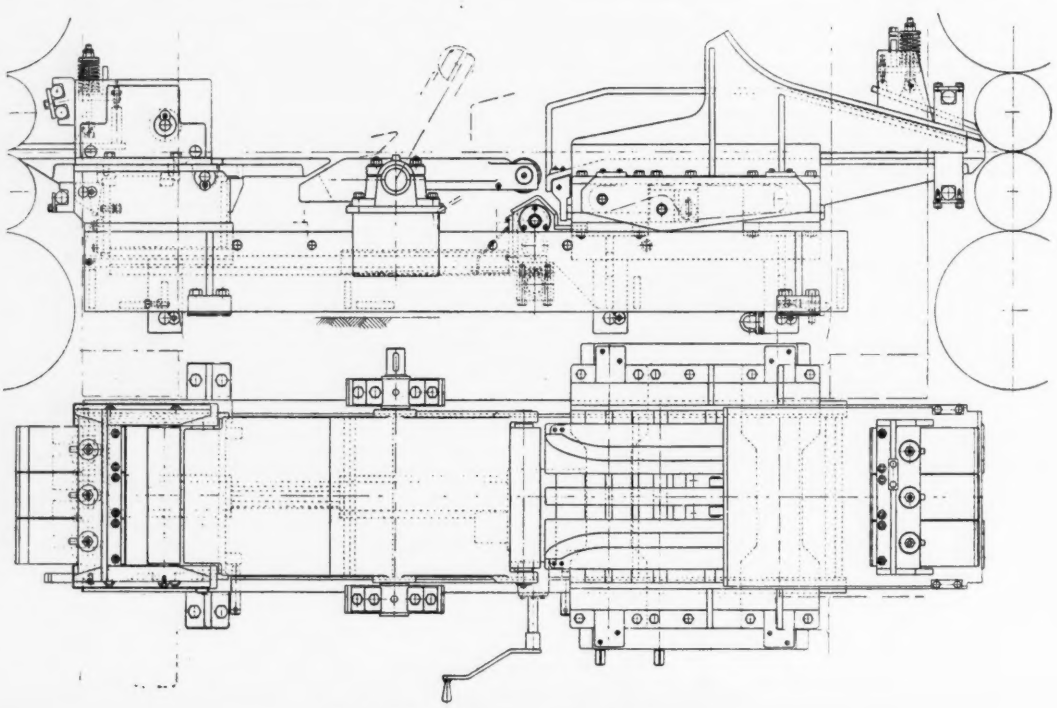

Fig. 5—Guides between finishing stands

being 305 ft. from the last finishing stand. This coiler is shown in Fig. 6. It consists of:

Two systems of side guides in front of the pinch rollers, one having a fixed opening for each strip width, leaving about $\frac{3}{4}$-in. clearance, the second being pneumatically closed to a predetermined opening as soon as the strip has entered the pinch rolls

A pair of pinch rolls, the top one having an appreciably larger diameter to exert a downward pressure on the strip when it enters the approach guide to the coiler

A mandrel driven by a 160-h.p. motor. The mandrel, which can be collapsed hydraulically, is surrounded by nine motor-driven guide rollers acting as a wrapper for the first windings of the coil.

Nine, instead of the orthodox eight, rollers surround the mandrel with the closest possible pitch, thus allowing even thin-gauge material to be guided at high speeds. The guide rollers are arranged on a lever system which is operated by two pneumatic cylinders to allow an individual radial movement for each pair of rollers. The gap between the closed-in guide rollers and the mandrel can be accurately adjusted, to suit the gauge of the strip to be coiled, by means of hand-wheel-operated eccentrics. After a number of windings the guide rollers are opened and the mandrel alone applies tension to the strip. This tension can be varied in accordance with the strip section.

The finished coil is stripped from the collapsed mandrel by a pneumatically operated pusher on to a receiving arm which tilts it into the horizontal position on to a table without sliding.

Figure 7 shows the coil evacuation. The aforementioned table is pneumatically shifted sideways until the coil is above the chain conveyor. Here a suitably designed revolving table takes over the coil, which in this position is wired radially in four places. In turning this table through 90° and lowering it by means of a hydraulic cylinder the coil is placed on a chain connected to a conveyor system which transfers it into the storage bay. The conveyor incorporates a weighing machine and an up-ender. Batches of coils are transported to storage by ram trucks.

Auxiliaries

To provide sufficient and effective descaling in the various stages of rolling, a 1250-lb./sq. in. water system has been installed and is connected to single banks of nozzles in front of roughing stands 1, 2, and 3 and to a double bank in front of finisher 1.

The water is supplied from two 450-h.p., 230 gal./min., multi-stage centrifugal pumps, and to cover for peak demands the system is equipped with an air-loaded accumulator station with four air bottles and one water bottle with a capacity of 110 gal.

Each of the spray headers is controlled from the operating platform by an electro-pneumatic valve.

Two main lubricating stations are situated in cellars below the motor bay: one serves the roughing train and the second the finishing train. Each station comprises:

Oil circulating system for main drives and pinion stands

Automatic grease system for numerous feeding points on the mill proper, including the roll necks, the grease lines for the neck bearings in the roughing train being normally isolated and only opened shortly before shut-down

Oil pressure system for the top roll balance with air-loaded rubber sac-type accumulators.

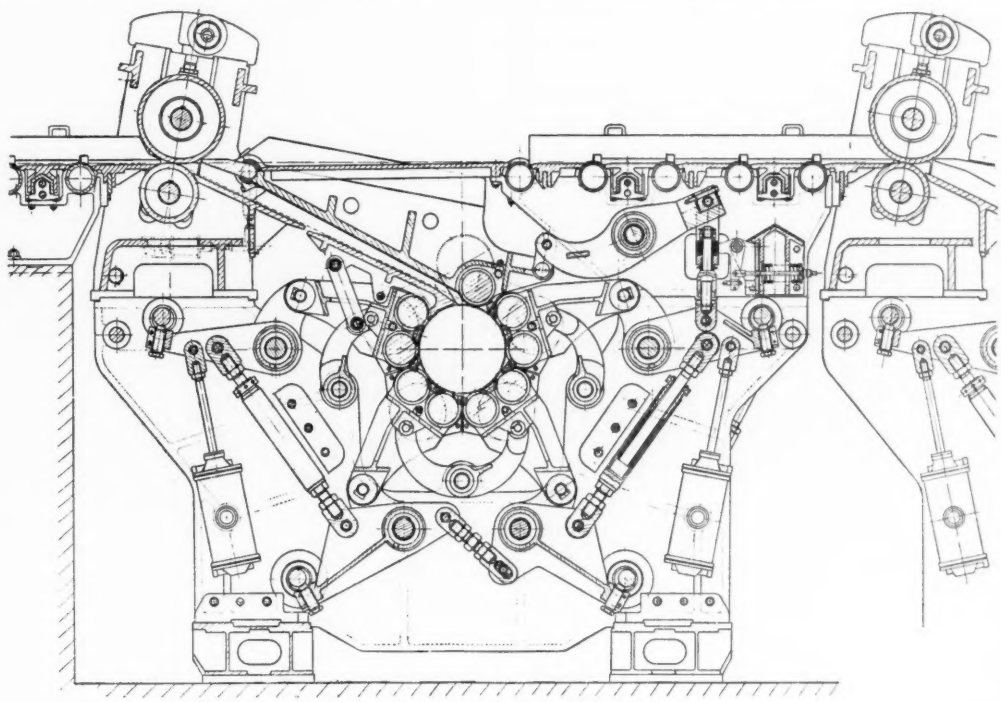

Fig. 6—Section of horizontal coiler

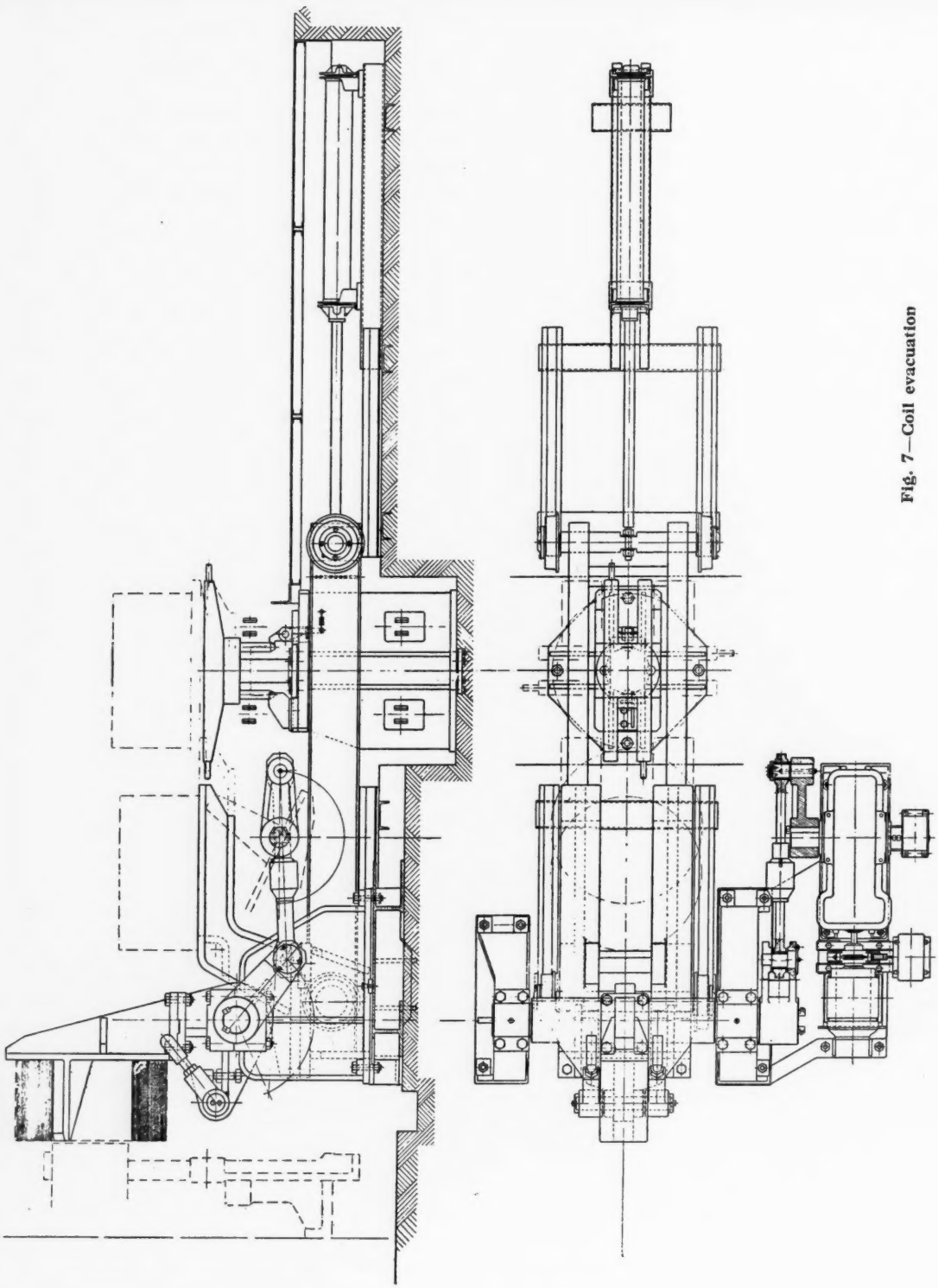

Fig. 7—Coil evacuation

A separate oil and grease station is provided for the coilers.

Cooling water is supplied at a maximum rate of 2600 gal./min. for the roll barrels and 2900 gal./min. for the spraying station in the finishing-mill run-out. The latter spray station is fitted with top and bottom jets arranged in three sections thereby allowing the regulation of the amount of cooling water in accordance with the desired coiling temperature.

Considerable attention was paid to the disposal of scale since only one collecting sump for the whole installation is situated near the reheating furnace.

In view of the importance of the proper control of temperature, four pyrometers are installed, one in front of rougher 1, one about 50 ft. in front of finisher 1, one close behind finisher 6, and one in front of coiler 1.

The temperatures obtained are indicated on large dials which, with the exception of that for the coilers, are visible from the mill floor and the control platforms.

An effective signalling system provides the necessary communication between the main operation points.

ELECTRICAL EQUIPMENT

Electric power is transmitted to the mill at 15,000 V. and 5000 V., the total available power being 22,000 kVA. The roughing-mill motors, descaling pump motors, and large lighting transformers are supplied direct from the 5000-V., and the rectifier transformers and the transformers for auxiliary motors from the 15,000-V. mains.

Three transformers, each of 1250-kVA. rating, feed the medium and small auxiliary motors. The 15,000-V. switchgear comprises low-oil-content circuit breakers with a rupturing capacity of 320 MVA., and the 5000-V. switchgear oil circuit breakers of conventional type.

D.C. auxiliary motors and the main motors for the vertical edging stands obtain power from a mercury-arc rectifier.

Roughing Train

As already stated, three identical motors of 1850 h.p., running at 500 r.p.m. synchronous speed, are installed for driving the horizontal edging stand and the four roughing stands.

To facilitate operation of the tandem stands a speed difference of about 10% between the two driving motors is obtainable by adjustment of the liquid starter-and-slip regulator.

Although a ratchet coupling is interposed between the edging-mill motor and the rolls, it was required that the motor and roll speed should be fairly closely matched, and that the slab should enter the horizontal rolls of the mill stand subsequent to the edging stand at a speed which corresponds closely to the roll speed, thus avoiding sudden shock or snatching. A D.C. motor is used with a very small amount of compounding. It has a speed range of 1:2 which is sufficient for all requirements.

All the auxiliary motors for the roughing train are of the A.C. slip-ring heavy-duty mill-type construction—a type often preferred to D.C. motors in Continental installations. All roller tables behind the first roughing stand are of the individually driven roller type; they have constant-speed, squirrel-cage motors, suitable for occasional stalling.

Finishing Mill

The flying shear is powered by a 180-h.p., variable-speed, D.C., mill-type motor, from a Ward-Leonard motor-generator set. The generator is a special amplidyne type, the more usual arrangement being a combination of amplidyne exciters and a generator of standard construction. The advantage of the type installed is an extremely quick build-up of generator voltage and acceleration of the motor—an important factor since the flying shear is used also for cutting the strip in an emergency.

The six 2000-h.p. finishing-mill motors receive their power from three mercury-arc rectifiers, each with an output of 3500 kW. The tanks are the mono-anodic pumped vacuum and water-cooled type, each installation being arranged in a 12-phase bank. Each rectifier transformer comprises two separate 6-phase windings; phase-splitting transformers are placed between each two 6-phase groups, thus virtually increasing the number of phases to 18.

Starting of the motors is by grid control. Voltage regulation of the order of 15% to take care of fluctuation on the A.C. side and voltage drop at load of the rectifiers is effected by electro-hydraulic regulators in the rectifier control grid circuit. They hold the voltage within $\frac{1}{2}$%, which is essential for accurate mill speed. All the motors are identical and are rated 2000 h.p. at 425–850 r.p.m. The choice of motor speed was dictated by the speed of the sixth stand, where drive is direct. This is an exceptionally high speed for motors of these dimensions but the running performance is satisfactory.

Considering the very high rolling speed, it is obvious that very close speed matching between the various stands is required. This is achieved by motors with a low impact speed drop, a small drop in speed with load, and fine adjustment in speed (*see* below).

In spite of the precise synchronization demanded, it was decided that automatic speed matching by means of amplifiers and pilot and amplidyne exciters could be dispensed with, and that all requirements could be reasonably met by incorporating the following features:

(*a*) Supplying each motor field from an amplidyne exciter, the variation in speed of the motor being obtained by a motorized vernier regulator acting on one of the amplidyne fields. This allows adjustment in very close steps, *viz.*, to about 0·1%.

(*b*) The motors are indirectly differentially compounded by feeding a further field of each amplidyne exciter from a shunt in the main motor circuit; any strengthening in the motor current will thus reduce the motor field, and compensate for the natural speed drop of the motors. This method allows the speed-load characteristics of the motors to be varied at will.

The amount of differential compounding depends, of course, upon the speed to which the motors are adjusted; an allowance for this is made automatically by rheostats which are coupled to the main motor field rheostats and are connected in the amplidyne

control fields. The drop in speed with full load can easily be limited to 1–2%.

By means of tappings provided on the rectifier transformers the mill can be run continuously at 10% below the basic motor speed or 10% above the normal rated speed.

Reduction in voltage by grid control to 30–40% is possible for short durations and is very useful for setting up the mill at reduced speeds.

The two edging mills are each driven by totally enclosed 60-h.p. mill-type motors, their operation and control being as for the larger motor driving the edging mill in the roughing train.

The loop-lifter motors have an adjustable stalling torque of 11–110 lb.ft.

Screwdown drives follow conventional lines with the exception that A.C. slip-ring motors are used.

Coilers

The roller tables between the finishing mill and the coilers comprise about 200 rollers individually driven by squirrel-cage motors; supplying them from three variable-frequency alternators, in turn driven by variable-speed D.C. motors, makes a total speed range of 1: 3·2 possible. It also allows the division of the roller tables into three sections which can be run at different speeds. This may be required to loop heavy-gauge strip so that it can enter the coilers below rolling speed.

The electrical equipment of each of the two coilers comprises the main drive for the coiler mandrel, the drive for the guide rollers, and the drive for the pinch rolls. The driving motor for the mandrel is rated at 130 kW., and has a range of approximately 6: 1, with a top speed of 1750 r.p.m.; this is to allow for the full rolling-speed range of the mill and to cater for the build-up in the coil diameter. These motors are somewhat over-dimensioned so as to make them interchangeable with the motors driving the variable-frequency alternators for the roller tables. The pinch rolls are powered by motors identical with the mandrel motors, their main purpose being to act as drag generators after the strip has left the mill. Only part of the power can, however, be transmitted through the pinch rolls to the strip, and an alternator coupled to the pinch rolls and used to supply power to the guide-roller motors, which thus are automatically synchronized with the pinch rolls, accounts for the total power required by the motors.

A motor-generator set is provided for each coiler, supplying mandrel and pinch-roll motors, but as it is necessary when operating coiler 2 to run both sets of pinch rolls, the first set acting as transport rollers, their motors can be switched over from one generator to the other.

Tachometer generators on the various stands of the finishing mill synchronize the coilers with the mill.

Constant tension and speed control of the mandrel motor to compensate for coil build-up is obtained by quick-acting segmental-type rolling contact regulators, an indication of the current being taken from the coiler generator interpoles and compared with a constant reference voltage. These regulators act on the field of the motor exciter which strengthens the motor field, thus reducing the motor speed with increase in current taken by the motor. A very satisfactory control of speed and a very wide range of tension in the strip is obtained with this system. Provision is also made for the maintenance of accurate speed control when the strip has left the mill and when tension is applied solely by the pinch rolls.

Control Platforms

As shown in Fig. 1, there are three main control platforms, *i.e.*, for the roughing mill, the finishing mill, and the coilers. Special care has been taken in the location and layout of these cabins to give the operators an uninterrupted view of all essential equipment to be controlled, as well as to facilitate handling of the numerous controls.

PERFORMANCE

The mill has been in full operation since November, 1951. Too short a time has so far elapsed to establish comprehensive data on its performance, particularly as, owing to the steel shortage, the plant can be operated for only one shift per day. However, the following information should be sufficient to judge the merits of the installation.

Types of Steel Rolled

The grades of steel which have been or will be rolled

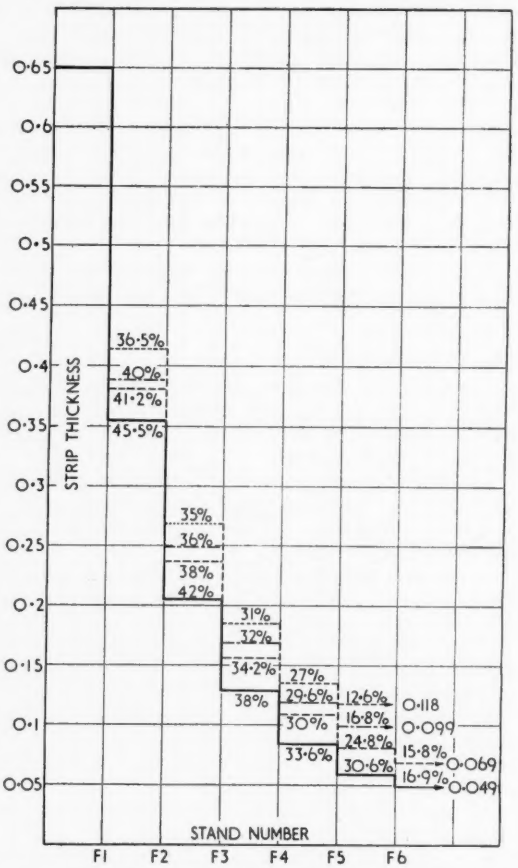

Fig. 8—Reductions in finishing mill

comprise basic Bessemer, open-hearth, duplex, and electric carbon steels (0·08–1·1% C); also Mn–Si and Ni–Cr electric steels of various qualities.

On an average, 42% of the output is supplied to tube manufacturers, 23% to cold rollers, and the remainder to various other consumers. So far the mill has produced mainly commercial steels of 0·2–0·4% C, and most of the undermentioned data apply to this quality.

Reductions

Owing to the constant slab thickness of 3 in., the setting of the roughing mill remains more or less the same for all strip sizes, giving reductions as follows:

Pass No.	Thickness, in. In	Out	Reduction, %
*R*1	3	2·28	24
*R*2	2·28	1·45	36·4
*R*3	1·45	0·95	34·5
*R*4	0·95	0·65	31·5

Typical draftings in the finishing mill for various strip gauges are shown in Fig. 8, from which it will be noted that gauges of 0·1 in. can be finished in stand 5. Gauges above 0·125 in. are frequently finished in stand 4 and even in stand 3. The maximum finishing speed is at present 2400 ft./min., but it is intended to increase this in the near future to 2800 ft./min.

The finished strip widths are about $\frac{3}{8}$–1 in. narrower than the slabs, the latter therefore being rolled in steps of $\frac{3}{4}$ in. in width. The average squeezing in the horizontal edging stand is $\frac{3}{4}$ in. and in the vertical stands it is roughly equivalent to the thickness of the ingoing section.

Operating Temperatures

The mill is usually operated with slab and strip temperatures as follows:

Entering the roughing mill: 1180° C.
Entering the finishing mill: 1070–1050° C.
Leaving the finishing stand: 950–875° C.
Entering the coiler: 800–700° C.

For the smaller gauges the strip temperature in front of the finishing mill is raised to ensure that the strip when leaving the finishing mill is still above the critical temperature of 840° C.

The foregoing temperatures vary for certain steels and also in accordance with the desired grain structure.

Output

The mill can be operated with a slab interval of 65–70 sec. for all strip sizes. Up till now only one or two slab widths have been rolled during each 8-hr. shift, each strip width being required in 5–7 different gauges. These frequent changes of the finishing mill setting affect, of course, the output; in view of this and considering that the average strip width has been 10 in., it is remarkable that a total average output of 45 tons/hr. of finished products has been achieved since the mill was put into operation.

With the above slab interval the maximum furnace capacity of 60 tons/hr. is absorbed when rolling strip 10 in. wide or more, and it follows that the ultimate maximum output of 100 tons/hr. with two furnaces is ensured when rolling strip with widths of 16 in. or more.

There is no doubt that the slab interval can be reduced to about 55 sec. once a suitable rolling programme can be arranged for a three-shift operation; in which case a maximum hourly output of 100 tons can be achieved for widths down to 12 in.; or, alternatively, with a third furnace 150 tons/hr. could be produced as a maximum for widths of 18 in. or more.

Conversion Data

The present frequent mill settings naturally also influence the loss through scrap, which amounts to approximately 3·5% of charged slabs. With long tonnage runs of one gauge only, this loss will be considerably reduced.

Since the plant is operating for one shift per day only, the furnace has to remain damped down for 16 out of 24 hr. This makes it impossible to record correct figures for the fuel consumption, but it is expected that the furnace will consume less than the guaranteed 22,600 cu. ft. of blast-furnace gas per ton of discharged slabs with three-shift operation.

The total scale losses in the furnace and mill amount to 2·5–3% of charged slabs.

The energy consumption for the mill proper, including its auxiliaries, averages 66·5 kW./hr. per ton of rolled strip. The total consumption, *i.e.*, including all overhead cranes, various auxiliary A.C. motors, lighting, battery charging, etc., is 83 kW./hr. per net ton (average). This consumption will certainly be appreciably reduced when the mill is operated on three shifts and with two furnaces. The required energy per net ton would then be substantially less than that of wide-strip mills.

The working rolls are cambered only when rolling strip with fine tolerances, say, above 20 in. wide. The rolls in the last finishing stand are changed after every shift if strips are rolled in the centre of the mill. When rolling narrow strip off-centre, these rolls remain in operation for two shifts. The finishing rolls can produce 400–650 tons between dressings and it is estimated that the average total life of one roll will amount to at least 20,000 tons. Considering that the price of the working roll is about 40% of that for a 60-in.-wide roll, and that the regrinding costs are appreciably less, the roll costs per ton of strip rolled compare not too badly with those experienced in wide-strip mills.

Initially, the finishing mill was fitted with alloy chill working rolls for stands 1–3, having a barrel hardness of 65–70° Shore, and Alloy Indefinite Chill rolls for stands 4–6, with a Shore hardness of 70–85°. New rolls with the maximum hardness are supplied only for the last finishing stand where they are used for 30–40% of their life before being employed in preceding stands.

The crew for each shift consists of one foreman and 29 operators, mill hands, and roll fitters, not including the personnel required for coil binding, storage, and maintenance.

Quality of Products

The slabs have a very clean surface due to the greatest care being exercised in the casting of the ingots and in rolling in the primary mills. Under normal conditions only 5% of the slabs have to be surface-conditioned, mostly on the edges. This is

Fig. 9—Coils in storage bay

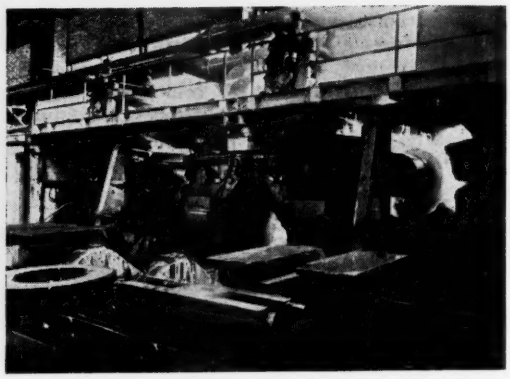

Fig. 10—Coiling of narrow strip

done either by pneumatic chipping or by flame scarfing.

The surface of the finished strips is beyond reproach, scale being noticeable only at the edges where air enters between the layers.

Gauge tolerances can be kept very close and it is not unusual to roll during a whole shift with tolerances of less than $\pm 0{\cdot}004$ in. This applies to all gauges, even above 0·125 in. and up to the maximum width. The tolerances on widths have also to be kept within a small margin, as a large portion of the output is supplied to tube manufacturers. These tolerances are within $\pm 0{\cdot}05$ in. for all widths. All tolerances are measured over the whole length of the strip, which is about 1350 ft. when rolling a gauge of 0·06 in. The coils are tight and neatly wound, as may be seen in Figs. 9 and 10, the latter showing a 1700-lb. coil of strip $6 \times 0{\cdot}06$ in. on the conveyor chain in front of the coilers.

SUMMARY AND CONCLUSION

The layout, design, and performance of a new continuous hot mill for strips up to 24 in. wide are described. It is hoped that this information will be of general interest and will help to prove that such an installation can be economically operated for a high output of medium-wide strip with a quality to suit all trade requirements.

Acknowledgments

The author thanks M. Liegeois, Director of Société Anonyme des Laminoirs, Hauts-Fourneaux, Forges, Fonderies et Usines de la Providence, at Rehon, for permission to publish this paper; and he is indebted to M. Trefois and M. Coic for much helpful information. The author also thanks his colleagues, Mr. Fernbach and Mr. Course, at the Loewy Engineering Company, Ltd., for their valuable assistance.

Atlas of Isothermal Transformation Diagrams

Special Report No. 40, published by The Iron and Steel Institute in 1949, is the first authoritative published collection of **S**-curves for the main types of wrought steel in current use in this country.

The data have been collected by the Thermal Treatment Sub-Committee of the British Iron and Steel Research Association, and represent the results of collaborative work by a number of industrial laboratories. The Atlas contains **S**-curves for 24 steels of the British Standards Institution En series detailed in B.S. 970. Each diagram is accompanied by a data sheet which records the compositions of the steel, its previous treatment, the hardness of the transformation products obtained at various temperatures, photomicrographs, and general comments which include reference to the hardenability of the steel.

A few copies of this report are still available at 25*s*. per copy, post free (15*s*. to Members). Applications should be made to the offices of the Institute at 4 Grosvenor Gardens, London, S.W.1.

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Electric Drives for Continuous Hot Mills

By G. R. Wilson, B.Sc.(Eng.), A.M.I.E.E.

SYNOPSIS

The paper reviews aspects of the electrical equipment used for the main drives of continuous hot mills. Reasons are given for some of the selections made.

Drives using one motor per mill and one motor per stand are considered, and, in the latter case, typical curves showing relative motor performance with different forms of control system are given.

Converting plant for supplying D.C. motors is reviewed, and comparisons are made between motor-generator sets and mercury-arc rectifiers.

Certain items of control gear are mentioned, and motor-rooms and their laycut are briefly reviewed.

Introduction

In a modern rolling-mill plant, whether for steel or for non-ferrous metals, the initial stage of reducing the cross-sectional area of metal from the as-cast condition always occurs in a heavy hot-reversing mill. The output from such a mill is usually in the form of blooms or slabs, which serve as the stock for further rolling in producing billets, strip, bar, rod, or the lighter sections. The hot reversing mill is an important unit, and attention has been paid to it in an earlier paper.[1]

Modern production ideas demand a continuous forward flow of material through a works, and a variety of rolling-mill arrangements have been developed that can act in co-ordination on a continuously moving piece of metal. These are termed 'continuous mills,' and the purpose of the present paper is partly to examine those aspects of design which affect the electrical equipment that may power or control them, and partly to consider the electrical equipment itself.

No two rolling-mill installations are ever identical, since each is laid down for a specified range of products, and to suit the purchaser. The term 'continuous mill train' has come to mean not only the arrangement in which a number of stands are closely set in tandem, so that they act together on a single piece of metal, but also arrangements in which most of the stands act in this way. The material moves forward all the time.

A continuous train of stands presents similar drive problems even if there are only two stands in the train, so that the definition 'continuous mill' is assumed to include any rolling mill in which there is a continuous train, even if all the stands are not so arranged.

Most continuous mills roll mild steel, but silicon steels, copper, and aluminium have been or are being rolled by these means. Two mills recently installed in this country contain continuous trains; one rolls wide aluminium strip and the other copper rod. Wide aluminium strip has been rolled in an American mill built for rolling wide steel strip.

BRIEF HISTORY OF CONTINUOUS HOT MILLS

Although continuous hot mills for rod rolling existed about 50 years ago, the greatest development has taken place during the past 30 years. During this period, bar, billet, and rod mills have greatly increased in power and speed, and the hot strip mill has grown to maturity.

Bedson Mills

Many years ago, in this country, Bedson proved the case for continuous mills, and the increased production to be obtained from them in comparison with the then more conventional looping or open mill. The early Bedson mills were for steel rod manufacture, and after the expected initial difficulties of such a progressive change had been overcome, they gave very good results. Twenty or more stands were set very closely in tandem, at 4–5 ft. centres, and were driven by a common steam engine.

Hot Strip Mill

The other form of continuous mill is that designed for wide flat products, generally termed the 'hot strip mill.' It was in 1924 in America that two steel firms eventually succeeded, after several years of intensive experiment, in rolling good-quality strip in large widths, and at a reasonable speed.

Since then, the basic ideas have changed little, although there have been many notable improvements, some purely mechanical and others affecting the driving medium. Some are the use of rotary-exciter control systems, electronic equipment, and mercury-arc rectifiers, while further improvements are not impossible in the continued efforts to obtain greater or better output.

CONTINUOUS HOT MILLS WITH SINGLE DRIVES

In early continuous mills, a number of stands were geared together and driven by a single steam engine, and later by a single electric motor. Such an arrangement, however, has practical limitations. Nevertheless, certain stands, such as the roughing stands of a wide strip mill, can be set far enough apart for the piece to be in only one stand at a time. These widely spaced stands precede a continuous train proper.

A.C. Drives

For driving widely spaced stands, an A.C. motor

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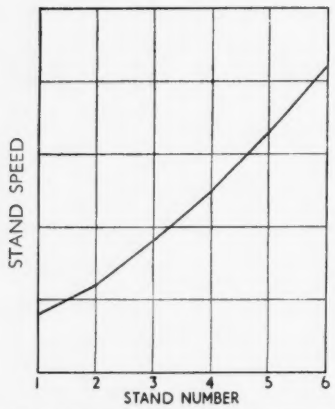

Fig. 1—Typical speed line for a continuous train with a single-motor drive

run from the usual supply is more efficient and less expensive than a D.C. motor run, *via* converting plant, from the same supply.

If the A.C. power-supply system is heavy enough to withstand the rolling peaks, which in roughing stands tend to be short and sharp, the synchronous motor is often selected, since the system power-factor adjustment possible with this type of motor has both technical and financial advantages; the smaller drives, however, are often of the slip-ring induction type, in view of the greater simplicity and lower initial cost.

If, however, the A.C. power system will not accept the rolling peaks, a flywheel must be introduced, when a slip-ring induction motor with slip resistance or automatic slip regulator is necessary; the flywheel will, however, usually be of little assistance on passes lasting more than a few seconds, and so needs proportioning to take the major part of the rolling loads on the initial passes only.

D.C. Drives

When a speed range is required on a roughing stand, D.C. power is the only modern method considered. The converting plant may be a motor-generator set or a mercury rectifier. Where a lower output is sufficient, or where a less expensive mill is required, several roughing stands may be replaced by one reversing rougher, for which the reversing D.C. drive with an Ilgner flywheel-set is the only solution. There are several wide continuous mills preceded by such drives.

TREND FROM SINGLE- TO MULTI-MOTOR CONTINUOUS TRAIN DRIVES

Single-Motor Drives

If any motor has to drive more than one stand of a tandem mill, at least one stand must have gearing and/or a different roll diameter to allow for the natural increase in speed of the material in progressing from stand to stand. Gears in the sizes usual on rolling mills are not adjustable in ratio in small amounts. The rolls have a certain effective diameter, according to shape, and are not adjustable except by turning or replacing. Thus, if two stands are driven from one motor, only a narrow range of percentage reduction figures can be obtained in the second stand, if the ingoing material speed at the second stand is to match the outgoing speed at the first. This practical limitation applies more forcibly as the number of stands increases, limiting the range of products that a continuous mill with a common motor can handle.

The bevel-gear sets connecting the motor lineshaft to the individual stands vary in ratio along the mill, giving the stands successively higher speeds: the percentage speed increase at each stand is fixed on an r.p.m. basis, and is still virtually fixed on a ft./min. basis, even after allowing for all the possible variations in roll diameter or grooving. Figure 1 shows the speed ' line ' for such a mill; it is given for comparison with Fig. 3, which refers to mills with an individual motor for each stand.

Single-motor multi-stand continuous mills for producing billets usually have synchronous or induction A.C. motors of about 5000 h.p. Motor speeds may be as low as 100–150 r.p.m., if the motor drives the bevel lineshaft directly, so that these motors may be very large.

Figure 2 shows a billet-mill drive of this type.

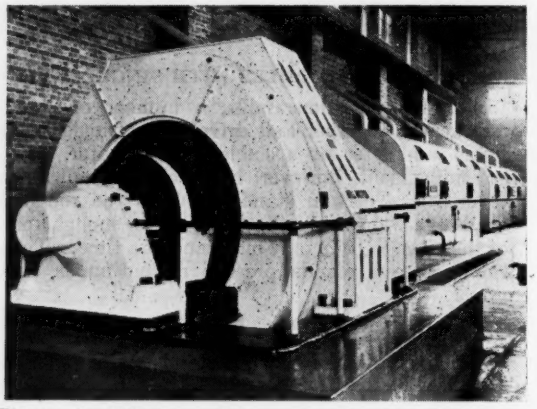

Fig. 2—A 6000-h.p., 500-r.p.m. slip-ring induction motor driving a billet mill through a gearbox and a bevel-gear lineshaft

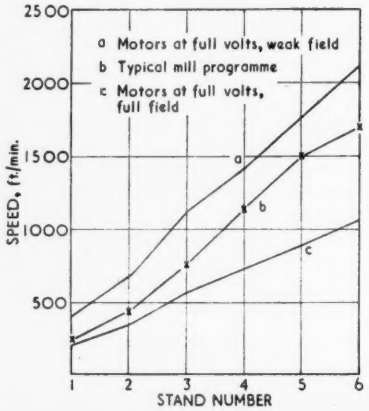

Fig. 3—Typical speed cone (or envelope) for a wide strip mill train with individual motors

The motor is a 6000-h.p., 500-r.p.m. machine of the slip-ring induction type, driving in this instance through a step-down gearbox to the lineshaft.

Large D.C. motors are often used on the finishing trains of rod mills; smaller ones are used to drive edging rolls associated with the A.C.- or D.C.-driven main rolls.

Multi-Motor Drives

For many mills, the collection of rolling programmes to be worked represents a fairly wide range of speed ratios from stand to stand; the desire to roll the lighter sections at higher speeds introduces another speed range in the mill. As a logical development, the mill drive was therefore broken down to a set of drives, each with a separate speed range; by setting the necessary speed on each motor, within its own range, the required overall speed range could be obtained for any product. The ultimate development is for every stand to have its own variable-speed motor, as in modern rod and wide strip mills. For this purpose, the shunt-wound D.C. motor, with a speed range adjusted by shunt-field control, is electrically excellent; it also gives an inherently greater torque at the lower speeds, when the heavier pieces are being rolled.

To select the motor speed ranges, all the known programmes for the mill are plotted as speeds at the several stands, as shown by the single programme line in Fig. 3; the motor speed ranges at the stands must cover the desired ranges, with margins at top and bottom, as shown by the two enveloping lines. There is at each stand a fairly definite maximum permissible speed range, dictated largely by the motor h.p. rating.

DETERMINATION OF MOTOR POWERS

The determination of motor power is normal, whether the motor drives one or a group of stands; the calculation is simplified by the continuous nature of the rolling and, compared with cold strip mills, by the omission of power transfer along the material.

A mill maker is usually interested in roll force,

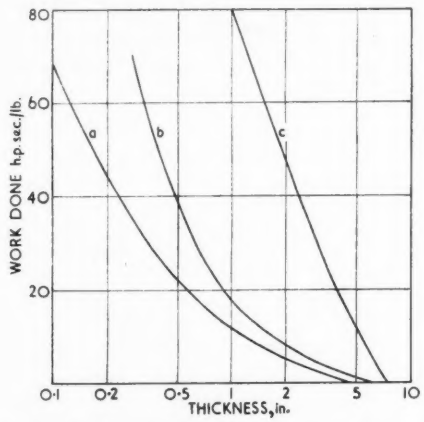

Fig. 4—Work-done curves for hot wide strip rolling (excluding mill light load loss). Curve *a*: Mild steel, 1200–850° C.; *b*: Aluminium, 550–250° C.; *c*: Typical hard aluminium alloy, 400–280° C.

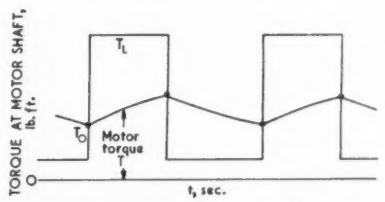

Fig. 5—Torque-time diagram for motor with flywheel assistance

lever arm, and other mechanical aspects besides torque and speed at the motor shaft. The electrical engineer is interested mainly in torque and speed, and so he tends to use work-done curves, such as those in Fig. 4, derived from test readings of volts, ampères, watts, and r.p.m., plotted in h.p.-sec./lb. or other similar work units against a base representing reduction or elongation. The simple calculation of lb./sec. through the mill leads easily to the h.p. load for rolling; allowance should be made for gearbox and other frictional losses, unless the work-done curve is based on a very similar mill and includes its inherent losses.

Since the average mill handles a wide variety of products, rolling-power calculations must be made for a number of the heavier programmes before suitable motor ratings can be stated.

Single-Motor Continuous Mill Drive

A motor driving a number of stands in tandem will have to carry for most of the time a load equal to the total of the several stand loads. For the different programmes, these totals will have a maximum value, which settles the basic h.p. rating of the motor. Motor speed range, if any, is a largely independent factor, although a particularly high total h.p. figure for one programme in a group can be reduced by running the motor and mill more slowly. If the motor is D.C., with a shunt-field range giving constant h.p. capacity, such a programme can be brought more into line with the others.

Roughing Stands of Continuous Mills

Each roughing stand usually has its own motor, which has to take the h.p. loads imposed on it. A motor without flywheel assistance has its basic h.p. rating fixed by the rolling h.p. loads. A motor with flywheel and slip resistance provides a more interesting problem, the solution of which depends on the basic equation:

$$T = T_L - (T_L - T_0)\Sigma^{-Kt} \quad (see \text{ Fig. } 5)$$

where
- T_L = mill load torque for the pass or interval
- T = motor torque at time t
- T_0 = motor torque at start of the pass or interval
- K = $\dfrac{P}{2ES}$
- P = h.p. rating of motor
- E = kinetic energy in motor and mill at motor synchronous speed, h.p.-sec.
- S = fractional slip at motor rated full-load speed
- t = time from start of pass or interval, sec.

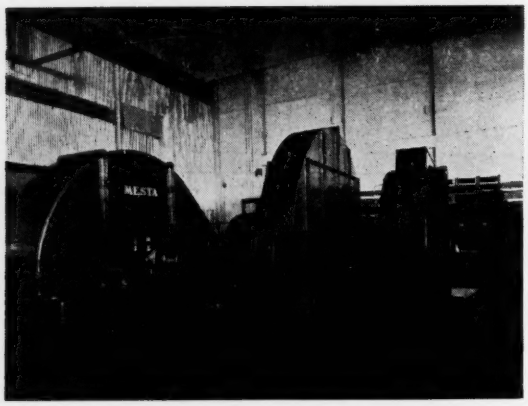

Fig. 6—A 2500-h.p., 150-r.p.m. slip-ring induction motor, with 37,500 h.p.-sec. flywheel, for the first roughing stand of a wide strip mill.

With careful design, the motor load can be kept fairly constant and the flywheel made to take the bulk of the actual rolling loads. In the first roughing stand of one British wide strip mill, a 2500-h.p., 150-r.p.m. induction motor (*see* Fig. 6) works with a 37,500-h.p.-sec. flywheel; they handle rolling loads of 12,000 h.p., each lasting about 1–1½ sec. By contrast, the second and third roughers of this mill are driven by 2500-h.p., 375-r.p.m. synchronous motors.

An analysis of many slip-ring and synchronous motor ratings for continuous mills and for roughing stands shows h.p. ratings of 1500–7000, and r.p.m. figures of 144–600, with no relationship at all between these two quantities.

Multi-Motor Drives

The problem of motor-power determination is complicated in the continuous train proper by the presence of a variable draft in each stand. In determining the h.p. rating of a motor, therefore, speed must also be taken into account. A collection of points in the plane given by a h.p. axis and a stand-speed axis is usually plotted for each motor, shown for a hypothetical three-stand case in Fig. 7. The speeds are kept in step from stand to stand, according to the various programme draftings, and the figure against each point represents the programme number.

Such a diagram shows readily if any programmes are abnormally fast or require abnormally high h.p. The maximum and minimum speeds for each stand can be selected, bearing in mind that motor design

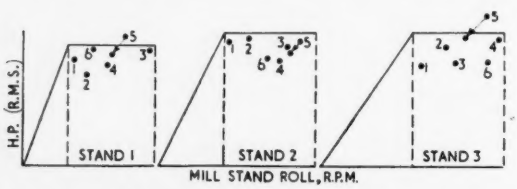

Fig. 7—Typical h.p./r.p.m. diagram for three stands of a continuous train. Programme 5 to be taken more slowly, to reduce h.p. ratings of two motors, by shifting points towards origin. Selected speed ranges would be 3/1, 2·4/1, and 2/1.

will often indicate practical limits for the speed range (by field weakening), and the basic motor h.p. rating becomes apparent at the same time.

If the speed-axis has been kept in terms of mill-roll r.p.m. the desirability of gear ratios will be obvious. A 4000-h.p. motor for a wide strip mill will have a normal speed range of about 150–300 r.p.m., so that it may be possible to use four identical motors for four stands out of a group of six, with perhaps two step-down gear ratios, a direct-drive, and a step-up gear ratio.

'R.M.S. and Peak'

The term 'basic h.p. rating' used previously refers to the rating before any r.m.s. factor is applied. In electrical machinery, it is the I^2R heating effect that largely determines machine size, and such machinery is therefore rated on an r.m.s.-duty-cycle basis: the r.m.s. equivalents of the various rolling programme loads must therefore be used in the selection of motors.

A truly continuous process has an r.m.s. factor of unity. Few continuous mills reach this ideal, since there are always intervals between pieces, although it is possible with some continuous mills, such as multi-strand rod mills, to get near enough to this ideal for the factor to be taken as unity.

Wide strip mills represent the other end of the range; a typical programme could easily be 50 sec. rolling and 40 sec. interval, which means that a motor on such a mill can be worked at 130% load while rolling, without exceeding either an r.m.s. factor of unity or the intended temperature rise.

The peak load expected on a motor, in terms of its r.m.s. rating, must also be considered. For continuous trains of stands, the peak will usually be well inside 1¾–2 times the r.m.s. and no problem arises. Roughing stands, however, have inherently peaky

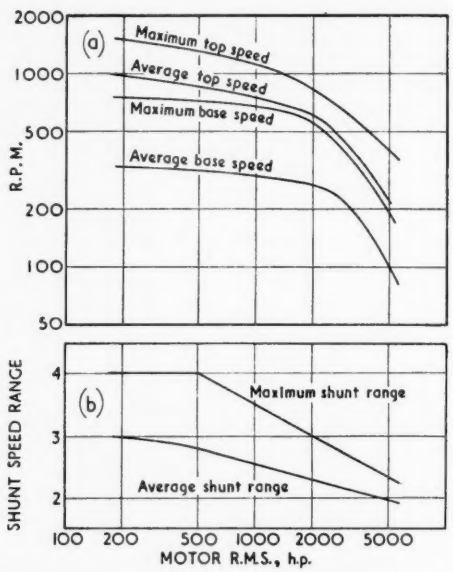

Fig. 8—Speed/h.p. relation for D.C. motors for continuous mill drives, based on many motors already made.

loads, and the peak r.m.s. ratio can easily exceed two. In such cases, either a special motor design is needed, or a larger standard motor, capable of taking the peak and so running cold, must be used.

An analysis of the r.m.s. h.p. ratings of many D.C. motors, applied to continuous hot mills, in terms of their base and top speeds and their speed ranges, produces the curves shown in Fig. 8.

There is a fairly wide ' spread ' of speed values and ranges for each h.p. rating, but the curves may help non-electrical readers who may be investigating new projects.

Electrical-machine designers can often design to special ratings, and can sometimes divide a motor into two armatures (a practice common on hot reversing and on cold tandem-mill drives), thereby reducing a difficult design to a practical one, but every effort should be made to standardize as much as possible.

Some Typical Motor Selections

Table I details the main motors applied to one of the British wide strip mills[2]; the motors of a typical British merchant mill are given in Table II.[3]

D.C. MOTOR PERFORMANCE AND CONTROL

When two or more motors act together on a common piece of hot metal, capable of withstanding only low inter-stand tension densities, there should ideally be no speed changes as the motors take up or cease taking load. This is particularly important on multi-strand rod rolling, where speed variations due to one strand starting and stopping should not affect the others. This calls for motors with zero regulation (or voltage drop due to load current), and, since this is unobtainable in practice, some compromise has to be adopted.

Inherent Motor Regulation

Many satisfactory equipments have been supplied with the motors designed for steady-state regulations of about $1\frac{3}{4}$–3%. Such regulations are usually achieved by motor design, without resorting to special control devices; the motor is thus larger than a normal industrial motor of the same torque rating would be. The top limit is $1\frac{3}{4}$–2% for motors that rely on their own internal design characteristics, on grounds of economy and since it is easy to get

Table II

MOTORS DRIVING THE STANDS OF A BRITISH MERCHANT BAR AND STRIP MILL

Stand No.	Motor Rating h.p.	Motor Rating r.p.m.
Roughing		
0 and 1	500	300/ 900
2	800	300/ 900
Edger No. 1	83·3/250	333/1000
3 and 4	800	300/ 900
Edger No. 2	50/150	333/1000
5	500	300/ 900
6	500	300/ 900
Edger No. 3	50/150	333/1000
Intermediate		
7	500	200/500
Finishing		
8	500	200/500
9	500	200/500
10	500	240/600
11	500	300/800
12	500	300/800

instability with slight design or site alterations if lower figures are aimed at.

Motor Regulation Improvement

Where regulations better than 2% are required, additional equipment must be used, which usually raises the initial cost and increases maintenance. Motor behaviour can be affected by acting on the shunt-field current supply and/or the armature voltage supply.

Shunt-Field Systems—Series windings on the main poles, carrying the load current, are theoretically possible when connected as a decompounding field. These are, however, not used, because the decompounding action is not readily adjustable; it is also undesirable, since it can lead to instability, especially on overload; the effect is greatest at weak field, and may be almost zero at full field. Introducing an exciter, fed from the voltage drop across the motor interpoles, to trim the shunt field, gives a more adjustable system.

An alternative method, shown in Fig. 9*a*, compares the speed of the motor, as measured by the voltage in a motor-driven exciter, with the main bus voltage; a control amplifier detects any error between these

Table I

DATA FOR MAIN DRIVES OF A BRITISH WIDE HOT-STRIP MILL

Mill	Work Rolls Dia., in.	Gear Ratio	Strip Speed, ft./min.	Motor h.p.	Motor r.p.m.
Roughing Scale Breaker	**2-high 24**	**17·55**	**179**	**600**	**500**
No. 1 Rougher	**2-high 32**	**20**	**210**	**2500**	**500**
No. 2 Rougher	**2-high 32**	**20**	**210**	**2500**	**500**
No. 3 Rougher	**2-high 32**	**13·1**	**320**	**2500**	**500**
No. 4 Rougher	**4-high 21**	**6·4**	**420**	**2500**	**500**
Finishing Scale Breaker	**2-high 24**	**12·8**	**147/441**	**400**	**300/900**
No. 0 Finishing	**4-high 21**	**6·33**	**196/392**	**3375/3710**	**225/450**
No. 1 Finishing	**4-high 21**	**4·4**	**281/562**	**3375/3710**	**225/450**
No. 2 Finishing	**4-high 21**	**2·75**	**451/902**	**3375/3710**	**225/450**
No. 3 Finishing	**4-high 21**	**1·89**	**654/1308**	**3375/3710**	**225/450**
No. 4 Finishing	**4-high 21**	**1·52**	**815/1630**	**3375/3710**	**225/450**
No. 5 Finishing	**4-high 21**	**Direct**	**925/1850**	**2800/3080**	**168/336**

voltages and trims the motor shunt-field current in the correcting direction. This is a proper speed-control system, and should give results better than those merely correcting for the effects of I.R. drop. The amplifier can take any of the recognized modern forms—rotating, electronic, or magnetic—according to preference.

Armature-Voltage Systems—The simplest way of improving motor regulation is to insert a booster excited from its own series winding, in series with its armature. This acts as a negative resistance to give the effect desired. In practice, some adjustability is needed, without loss of response rate, and so control exciters have been introduced in some cases; it is thus possible to control the booster armature voltage in proportion to the voltage dropped along the motor interpoles.

Since, however, the motor speed regulation may not be exactly the same as the I.R. drop regulation, a speed-control system is better than a system that merely reduces the I.R. drop, especially when the causes of impact-speed drop are considered. The circuit shown in basic form in Fig. 9*b* is that of a speed-control system acting by adjusting the armature voltage.

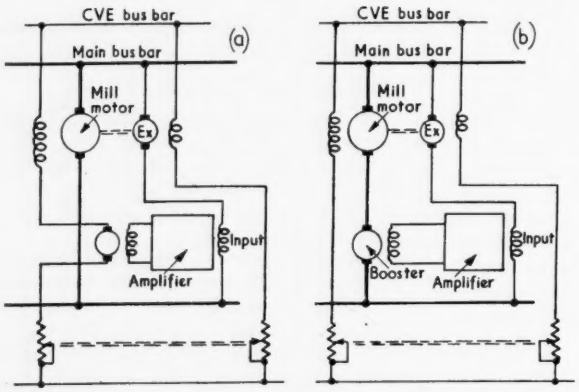

Fig. 9—Two ways of controlling the speed of a D.C. motor driving one stand of a continuous mill: (*a*) Field control; (*b*) voltage control

The speed is measured as a voltage in a pilot-exciter driven by the motor, and is compared with the main bus-bar voltage. Any error is amplified and is used to excite a booster in the motor armature circuit. This is a true control system, and can easily be designed to give effective regulations of 0·25% or better.

Impact Speed Drop

Whenever a piece of material enters or leaves a stand, the rolling-load torque changes abruptly. Owing to the inevitable electrical inertia in the motor armature circuit, the motor current cannot change instantaneously to the value corresponding to the new load torque; until the current has changed, it cannot provide the proper amount of load torque, and the difference between the load torque and the current-equivalent torque must therefore come from a change in kinetic energy of the drive. Thus the load impact causes a speed drop when a piece enters the mill, and a speed rise when it leaves.

When the armature current has changed to its final value and can supply the load torque, the speed again becomes constant, but at a value differing from the initial value because of the motor regulation.

Many parameters enter into the choice and determination of impact-speed drop and the speed-recovery effects: the basic equations for the simpler scheme of a motor without any controlling influence have been published elsewhere. The following should be noted:

(i) A certain degree of overshoot in reaching the final steady-state condition is usually permissible, and in some cases may even be desirable.

(ii) Conditions are worst with a motor on full-field setting, when, owing to the lowered speed, there is the least kinetic energy available to resist the impact-speed change.

(iii) A motor controlled by one of the schemes mentioned usually shows a reduced percentage speed drop under impact load, a shorter time to the greatest drop in speed, and a quicker recovery, than does a plain uncontrolled motor relying on its inherent properties. The importance of quick response depends on the type of mill; billet mills tend to be slow, and can operate successfully with 'inherent' motors, whereas rod mills reach such high speeds that the 'inherent' motor may not respond rapidly enough.

Some typical curves showing the calculated effect of a modern control system are given in Fig. 10. A medium-sized motor of 700 h.p., 575–1150 r.p.m., has been selected, and alone would have an inherent regulation of about 2%.

Curve *a* represents the speed change of the uncontrolled motor when subjected to impact application of full-load torque, and curves *b* and *c* represent the speed changes, under the same impact load, of the motor working with the two different control systems shown in Figs. 9*a* and *b*.

The advantages of providing a control system for each motor are apparent from Fig. 10. The area above a curve and up to the final-speed line represents lost revolutions after impact load is applied; lost revolutions mean looping in the material immediately before the stand concerned and stretching in the material after that stand. Thus the area above the curve is another important factor in the application and design of motors for continuous hot-mill drives; some overshoot in the control system and in motor

speed is beneficial, because it reduces the total of lost revolutions.

Similar control systems can be designed for almost any requirement, but the complexity and cost of the complete equipment will rise as the inherent performance of the motor alone is improved.

Motor Design in General

Regulation and impact-speed drop are the two major aspects in the design of a continuous-mill motor; nevertheless, the following notes are given to make this section of the paper complete.

Electrical—Motors are invariably compensated, with no series turns at all, and usually operate at armature voltages between 400 and 700, with 600 as the commonest voltage. Standard overload capacity is usually adequate, *i.e.*, 25% excess current for 2 hr., or 100% momentarily.

Temperature Rise and Insulation—Temperature rise is usually limited to that consistent with class *A* insulation, but although the armatures usually have this insulation, class *B*, with its higher temperature limits, is sometimes needed on the field system. At the same time, the full temperature rise may not be attained on the armature because the machine D^2L has been increased in the interests of better regulation and impact-load performance.

Mechanical—The speed changes due to impact loads mean the use of heavy-duty construction, as in other steel-mill motor applications.

CONVERTING PLANT FOR D.C.-FED MOTORS

In rare cases, a D.C. motor may be supplied from a general-purpose works' D.C. system. Its voltage is usually erratic, such that a precision mill cannot be operated with the accuracy required.

In most cases, therefore, a separate D.C. supply is provided, solely for the group of D.C. motors on a continuous mill, and, to minimize the effects of one motor on the others, a voltage regulator maintains the system voltage within $\pm 1\%$ of the desired value. Motor-generator sets are the obvious practicable answer, but the mercury rectifier has recently been gaining ground steadily, so that both forms of converter must be considered.

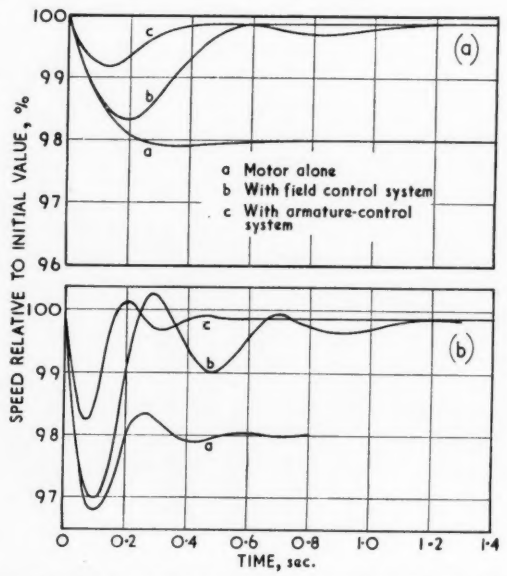

Fig. 10—Estimated speed/time curves for impact full-load application: (*a*) At weak field; (*b*) at full field

Motor-Generator Sets

Standard generators are driven by synchronous or induction motors. Synchronous drive gives the opportunity of correcting the system power factor, but costs more. Generators may be in parallel to provide any total kW. output needed.

Generators that operated only at their normal voltage were used for many years. Every D.C. motor then had to be provided with its own multi-step resistance starter, which was often of the contactor type, to permit automatic starting from the control desk, but this was expensive.

A development, originating in this country, that is now standard, was to use the generators in the Ward-Leonard way, dispensing with most of the equipment in each motor starter and replacing it with a motor-driven rheostat acting on the generator field. Motors are started by being connected to the D.C. bus at zero voltage, and the generator is then brought up to the normal voltage. The benefits are smoother starting and much less control equipment.

Mercury-Arc Rectifiers

Rectifiers are very suitable for supplying non-reversing D.C. motors that are started infrequently, at light load, and run steadily for long periods at a set voltage.

Performance equivalent to Ward-Leonard generator working can be obtained with mercury-arc rectifiers fitted with grid-control circuits. Although grid control gives smooth and easy starting, its mere application causes the A.C. system power factor to deteriorate by roughly the percentage depression in D.C. voltage below normal. The power factor will thus be poor at low D.C. voltages, but if grid control is used mainly for starting, when the kW. load is obviously low (as there is no metal to roll), the kVA. must be correspondingly low, and a poor power factor only introduces a low value of lagging kVA. into the A.C. system. Transformer tappings are now usually provided for the D.C. voltages needed when on load, and the grid control is used only to bring the motors up to the selected voltage and to maintain constant the D.C. voltage provided by a transformer tapping. In this way, the normal operating power factor can readily be kept better than 0·8 or 0·85 when on load.

Although American manufacturers favour single- or multi-anode pumped steel tanks, with all their ancillaries, the preference in Great Britain is for sealed multi-anode air-cooled steel tanks because of the simplification in the ancillaries.

The number of phases in the rectifier circuits depends on:

(i) The size of the installation in relation to the size of the A.C. system in the immediate vicinity, and to the size of the power-supply system

(ii) The number of rectifier transformers in the installation.

Although transformers can readily be made for six or twelve phases, a greater number of phases means having more than one transformer. In very large installations it may be worth using 24- or even 36-phase conversion; this may also apply to smaller equipments on power systems of limited capacity. Six-phase conversion seems quite satisfactory for outputs of up to about 2000 kW., and twelve-phase for up to about 10,000 kW., when considered in relation to the average large steelworks supplied from the British Grid System.

Choice of Motor-Generator Sets or Rectifiers

The advantages of rectifiers over motor-generator sets are greater efficiency, lower initial and maintenance costs, and easier foundations.

The efficiency of a motor-generator set is not likely to exceed 88–90% at full load, whereas a rectifier equipment can often have a full-load efficiency of 92% or better. The light-load losses of a rectifier equipment are lower than those of a motor-generator set; the reduction in these losses can be valuable on many mills in view of the proportion of the total time usually spent in light-load running.

The initial cost of machines and transformers is a function of kW. rating rather than of current, and the opposite is more true of rectifiers themselves. As the D.C. voltage rises, the current and the number of rectifier tanks for a given kW. rating fall. The cost of grid-control gear and transformer tappings is roughly constant and becomes less noticeable at the higher kW. ratings. Thus, for the outputs of the order needed for supplying D.C.-motored continuous mills, the initial cost of rectifiers is usually less than for the corresponding motor-generator set.

Maintenance costs of rectifiers should be below those of motor-generator sets; generators have wearing parts, mostly numerous brushes, but transformers require virtually no maintenance or replacement of oil, and most rectifiers have very few wearing parts.

Foundations are much simpler, lighter, and less expensive for rectifiers.

For most continuous or continuously running mill-drive applications, the advantages offered by motor-generator sets seem to be :

(i) Opportunity for system power-factor correction if synchronous motors are used to drive the sets

(ii) Performance proved over a greater number of years (this point is becoming less valid)

(iii) A preference for motor-generator sets in certain tropical countries, since high ambient temperature may cause a greater derating on rectifiers than on machines

(iv) Emergency motor reversal is easier, since the generator voltage can easily be reversed ; with a rectifier system, motor reversal usually needs, for each motor, a motor-field reversing switch in the pulpit or motor-room

(v) Greater independence, on the D.C. side, of A.C. voltage fluctuations.

Extent of Rectifier Application

Rectifiers have been applied to a number of main roll drives. According to the information available to the author, installations already working or on order total about 42,000 kW. in the United States, 40,000 kW. in Great Britain, 66,000 kW. in Europe, and 30,000 kW. elsewhere. Of this large total, American manufacturers have built or are building about 90,000 kW., and British manufacturers about 73,000 kW. In the United States, 14,000 kW. of rectifier capacity are assisting motor-generator sets, and in this country about 10,000 kW. of rectifier capacity are similarly planned.

Determination of Converting Plant Capacity

Where a converting unit supplies a single D.C. motor, the rating of the former must equal that of the latter. Where a converting unit supplies a number of D.C. motors, a diversity factor exists unless the mill is designed for only one product. The aggregate h.p. rating of the several D.C. motors is usually more than the total h.p. required on the mill at any one time, even when allowance is made for r.m.s. duty-

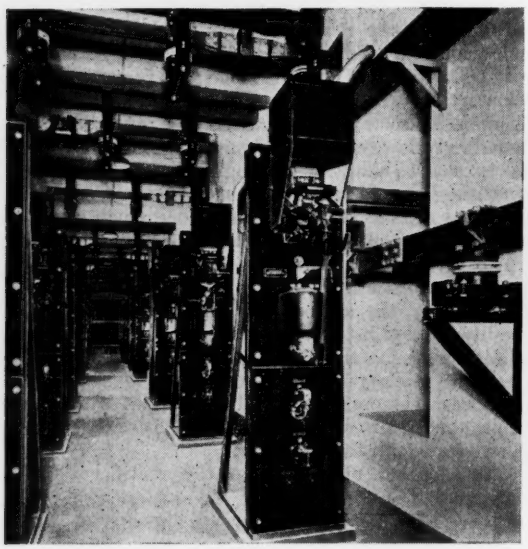

Fig. 11—Basement switch-room for the finishing mill motors and motor-generator sets of a wide strip mill

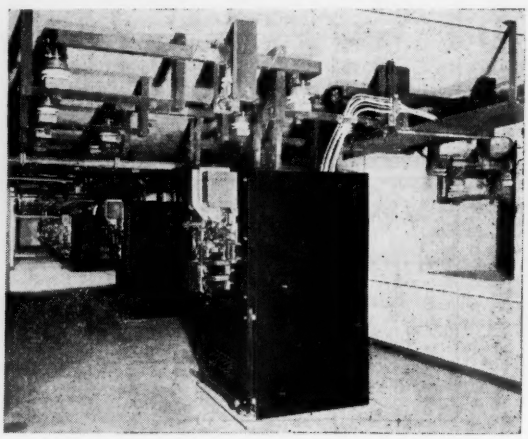

Fig. 12—Basement for part of a hot mill drive, with circuit-breaker panels for roughing-mill motors and their generator

cycle effects. The true converting plant rating should then match the highest total r.m.s. h.p. required on the mill for any product likely to be rolled for more than about an hour at a time. It is sometimes difficult to arrive at this rating, especially if all the likely heavier mill programmes are not, or cannot be, analysed in detail. It has been learnt from past equipments that the diversity factor between converting plant kW. rating and aggregate D.C. motor kW. equivalent rating is between 0·5 and 0·9, with rod mills tending towards the lower and wide strip mills towards the higher factor.

Effect of Rolling Load on A.C. Power System

The worst type of mill from the power system aspect is the wide modern hot-strip mill, since the nature of the periodic rolling (one piece every 90 sec. or so, probably 50 sec. on and 40 sec. off) demands about 30,000 kW. while the piece is in all the five or six stands, and perhaps only 1500 kW. (*i.e.*, about 5%) when there is no piece in the mill. The load builds up in sudden steps of about 5000 kW. at a time, at intervals of roughly 1 sec., and falls away equally abruptly. Such a fluctuating load is a severe test on the stability and governing properties of steam turbo-alternator sets, unless the power system is so large that the 30,000 kW. load fluctuation tends to be lost in the total steelworks load or the total grid system load. As much other reasonably constant load as possible should be connected to the same power system, so that the power stations do not feel the fluctuations.

A 3- or 4-strand rod mill provides the least power-system disturbances, since the rolling is often virtually continuous on each strand. Any stand of a four-strand rod mill would normally take a load fluctuating between 78 and 100% (instead of between about 5 and 130% on a wide strip mill), and as only perhaps five or six stands are empty of one strand at a time the A.C. load for the whole mill alters only slightly.

CONTROL GEAR

It is not intended to review common requirements, such as protection for overload, overspeed, or field failure, but only to review some of the more special items.

Main Bus Bars and D.C. Breakers

The commonest arrangement of the main D.C. equipment on a continuous mill has a single common bus bar, which is fed by all the generators and/or rectifiers and which in turn feeds all the motors. There is, however, a tendency to divide the bus bar into two or more sections for either or both of two reasons :

(i) The total short-circuit power that can arise on a modern large mill equipment may be so great that suitable breakers are not readily obtainable. In an equipment with six 5000-h.p. motors and 20,000 kW. of generators, the short-circuit current may reach 800,000 amp. High-speed breakers help to reduce damage to machines by tripping due to rate of current rise and before the maximum current is reached, but there is still likely to be a problem. The rapid current break given with a high-speed breaker may, however, cause high inductive voltages on machines and so lead to other damage

(ii) The division of the bus bar into sections permits the system, by the installation of extra voltage regulators, to operate at several voltages ; a particular mill product, rolled only occasionally, may require an overall range of stand speeds too broad for the normal range of products, so that by running the earlier stands at reduced voltage the mill flexibility can be greatly increased.

Figures 11 and 12 show two arrangements met in practice. In Fig. 11 the positive and negative bus bars and breakers are on opposite sides of a basement, situated between motor-generator sets and motors ; the possible short-circuit effects are thus reduced a little. In Fig. 12, a compact double-pole breaker unit is located behind each motor foundation pit.

Operators' Pulpits and Desks

There may be three or four pulpits, or elevated

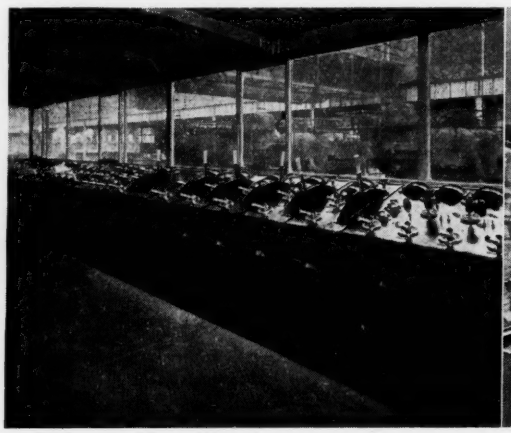

Fig. 13—Finishing-mill control desk for main motors, generators, and other equipment on a wide strip mill

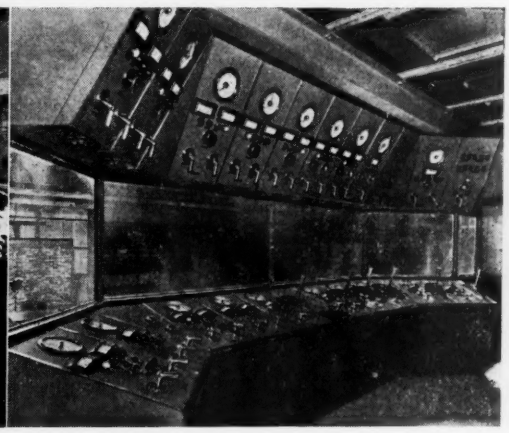

Fig. 14—Main control pulpit for a merchant mill; controls on the upper section are for certain roughing motors, the generators, and other plant, and, on the lower section, for the remaining roughing motors and the intermediate and finishing motors

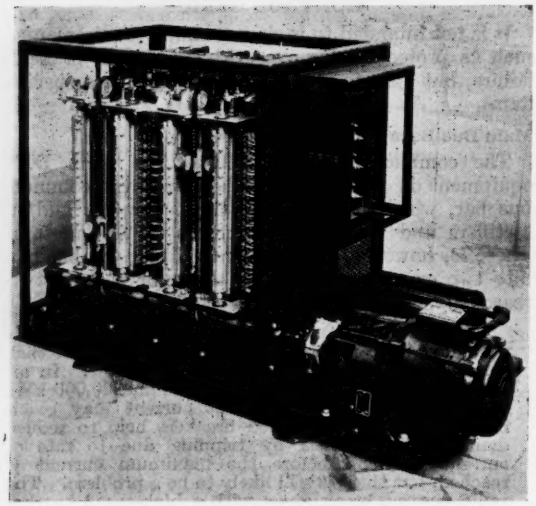

Fig. 15—New motor-driven rheostat with in-line contacts (cover plates removed)

control cabins, overlooking the mill and placed in positions giving good visibility, although two usually suffice. A continuous train can be seen reasonably well from the drive side, and rather better from the non-drive side: in the former case, the numerous electrical cables from the pulpit to the motor-room are shorter than in the latter, so that the better visibility from the non-drive side means accepting the presence and extra cost of a cable tunnel across the mill.

The control desk in a mill pulpit must carry much equipment, as shown in Figs. 13 and 14. Each D.C. motor needs means for starting and stopping, and for adjusting its shunt-field setting ; ammeter and speed indicator are also essential. Each section of the bus-bar system needs control devices for changing its voltage, and various other equipment may be needed for overall mill control.

Motor shunt-field setting has often hitherto been effected by a power-driven ' coarse ' rheostat in the motor-room, which responds to movements of a control switch on the desk ; fine or vernier trimming was obtained from a rheostat in or under the desk, and operated from a lever in the desk top as shown in Figs. 13 and 14. This practice is still in use, but another method is being used increasingly to improve the electrical performance and at the same time make the desks more compact. The fine-control rheostat is designed with all the contacts in a straight line, to minimize the width, and the number of contacts is increased to 300 or more, so that control is available, from the one rheostat, over the whole range. The desk can thus be built with only 14 in. length, or less, for each motor, and yet will accommodate in this length, and below the desk floor, a two-track or two-circuit rheostat. One control switch is eliminated on each motor section of the desk and the separate motor-driven rheostat with its contactors and other control items is also eliminated. Figure 15 shows a rheostat of this new design, with, in this case, motor drive and four separate 120-way rheostat units in the one assembly.

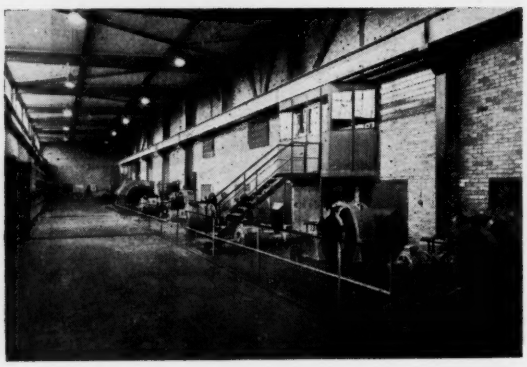

Fig. 16—Motor room for finishing train of a narrow hot-strip mill for stainless and mild steels. There are five stands and two edgers, each with their own motors; the edger motors are partly below floor level

MOTOR-ROOMS AND THEIR LAYOUT

In hot steel mills, there is much dirt, which is not conducive to long life of electrical plant; as much of the plant as possible should therefore be located in a properly constructed and ventilated motor-room.

In most continuous mill trains, the motors are side by side on one level, with or without being staggered, but modern practice for mills other than those for strip seems to favour building some of the stands, perhaps alternate ones, with the rolls vertical. Motors for these vertical stands will be above or below the general motor level, and so cause an extra building problem, but if a basement can be incorporated in the scheme, the building problem may largely disappear. Figure 16 shows a set of mill drives coming between the two cases mentioned : the vertical edger rolls are driven by motors several feet below the general motor level.

The motor-rooms of Figs. 16, 17, and 18 all contain

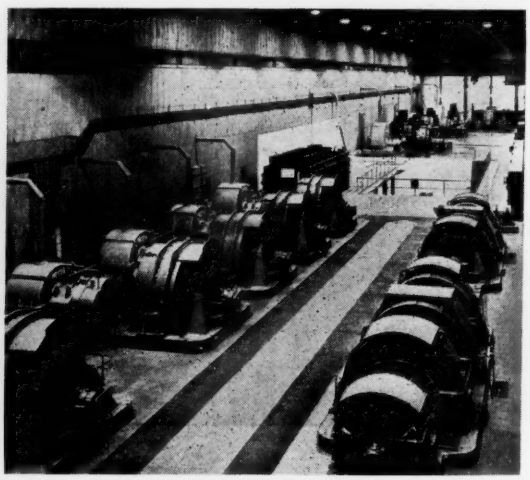

Fig. 17—Motor-room of a British wide strip mill, with roughing-mill drives in the background, finishing-mill drives on the left, and their motor-generator sets on the right

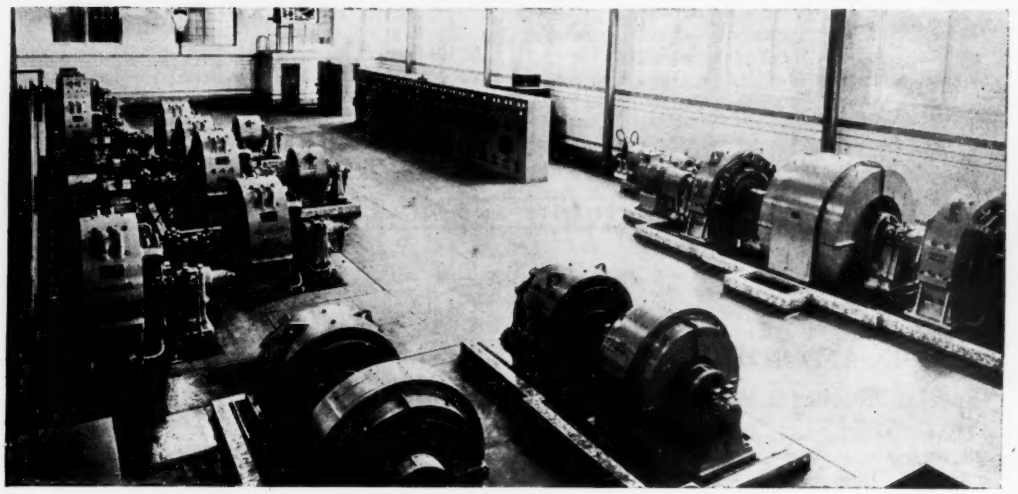

Fig. 18—The main machines associated with a merchant rod and strip mill: Mill motors and edger generators on the left, motor-generator set on the right, and central control board in the background

basements, the motor and generator circuit breakers and other gear, such as remote-controlled rheostats, being installed in the latter. The circuit breakers of Fig. 11 are in the basement between the motors and the motor-generator sets shown in Fig. 17, giving a very compact arrangement.

With some of the electrical equipment in the operating pulpits, and with the circuit breakers and other gear power-operated for operational ease, a centralized control board, such as that in Fig. 18, becomes necessary, from which the various exciter and main sets, fans, etc., can be started, and from which the mill operators can be given 'permissive control.' This board will also carry all relevant indicating and recording meters.

In most equipments, ventilation is needed for some machines and for the motor-room. Varying conditions require different systems ; most of the simpler systems have the motor-room on the ' warm-air ' side of the system, but this can be inconvenient in some climates. If the motor-room is purposely kept on the ' cool-air ' side of the system, or if it is excluded from this, machine commutators may require enclosure and so lead to more difficult maintenance.

Motor armatures may run cool if they are designed for close regulation, but such a design can require high field power. Forced ventilation may thus be necessary because of the field losses. If the motor is designed for a wide shunt range, or for a low speed relative to its normal speed for the number of main poles fitted, a self-driven fan will be nearly useless, so that forced ventilation is required. On the other hand, generators can usually be ventilated naturally.

If the motors do not need much forced-air supply, an air opening can be provided in the foundations below each commutator ; air is taken from the motor-room, down past the unenclosed machines into the basement, and then through coolers and back to the motor-room. This arrangement gives a cool motor-room, but does not fit in too well with rectifiers, which normally need an upward air flow. Each equipment often has to be considered on its own, with a ventilating system designed to suit the particular circumstances.

Another aspect requiring careful consideration is that of space. The Factories Acts specify minimum clearances between equipment and structural work, but these minima should be exceeded to get good accessibility and easier maintenance, and to reduce accident risks. If there is more space, the overall appearance of the equipment as a whole is enhanced, and this often leads to better maintenance. Ventilation is easier, since ducts interfere less with cable runs and foundations, and free air-flow into or out of machines gives lower air velocities in the main walking spaces. A small motor-room is difficult to ventilate and is hotter; it is also likely to be noisier, causing greater discomfort to the attendants.

AUXILIARIES

No modern mill can work without a large number of varied auxiliaries, such as upcut and flying shears, runout tables, cooling beds, screwdowns, and pumps. These all need electric drives and create many problems. Electrical equipment for auxiliary functions has been described previously, and could well be the subject of further papers. It is not proposed to deal with any of this equipment in the present paper, beyond noting that careful co-ordination with the main drive equipment is required if a successful mill is to be achieved.

Acknowledgments

The author wishes to thank several colleagues for valuable assistance and comment, and the English Electric Company, Ltd., for permission to publish the paper.

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1. P. E. Peck : *J. Iron Steel Inst.*, 1951, vol. 167, pp. 309–323.
2. H. S. Carnegie : *English Elec. J.*, 1939, vol. 9, No. 7, pp. 204–212.
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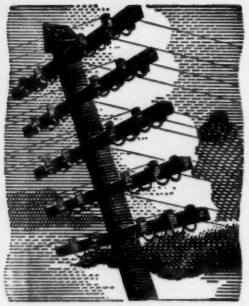


N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Special Meeting in Swansea, 1952

The Council of The Iron and Steel Institute have accepted an invitation from the Mayor of Swansea to hold a Special Meeting in Swansea from **7th to 9th October, 1952.** A reception Committee has been formed under the Chairmanship of Colonel J. M. Bevan, D.L., M.C., J.P., to make the arrangements in South Wales. Sir Lewis Jones, J.P., South Wales Siemens Steel Association, and Mr. P. O. Williams, Welsh Plate and Sheet Manufacturers' Association, have kindly agreed to act as Honorary Secretaries.

Programme

Members and Ladies will arrive in the Swansea district or Porthcawl on the evening of **Monday, 6th October.**

Tuesday, 7th Oct.

At the invitation of the Chairman, Mr. E. H. Lever, and of the Board of the Steel Company of Wales, Ltd., Members and Ladies will visit the Trostre Works of the Tinplate Division of the Company.

In the evening there will be a Reception and Buffet in the Brangwyn Hall, Swansea, given by the Mayor of Swansea.

Wednesday, 8th Oct.

In the morning, Members will visit the Margam Works of the Steel Company of Wales Ltd., (coke ovens, blast-furnaces, and steelworks) ; Ladies will have the morning free.

In the afternoon, Members and Ladies will visit the Abbey Works of the Company (new steelworks and strip mills).

In the evening there will be a Banquet and Dance at the Brangwyn Hall, Swansea.

Thursday, 9th Oct.

All day : Motor Bus Excursion to Llanwrtyd Wells and Mid-Wales (available to Members and Ladies)

or

Motor Bus Excursion to Tenby (only available to Members and Ladies accommodated in the Swansea, etc., districts).

Morning : Visit to *one* of the following (available to Members only) :

Aluminium Wire and Cable Co., Ltd., Port Tennant, Swansea.

British Iron and Steel Research Association, Sketty Hall, Swansea, and University College of Swansea.

Imperial Chemical Industries, Ltd., Waunarlwydd, Swansea.

Metal Box Co., Ltd., Neath.

Mond Nickel Co., Ltd., Clydach, Swansea.

National Oil Refineries, Ltd., Llandarly Works, Skewen, Neath.

National Smelting Co., Ltd., Llansamlet, Swansea.

Steel Company of Wales, Ltd., King's Dock, Swansea.

Afternoon : Motor Bus Excursion to Gower and District (only available to Members and Ladies accommodated in the Swansea, etc., districts)

or

Motor Bus Excursion to the Vale of Glamorgan and Ogmore-by-the-Sea (only available to Members and Ladies accommodated at Porthcawl.

The evening will be free. Informal Dances will, however, be arranged at the Caswell Bay Hotel, Caswell Bay, Swansea, and at the Seabank Hotel, Porthcawl, for Members and Ladies who wish to attend.

Members and Ladies will leave the Swansea district and Porthcawl on **Friday, 10th October.**

Visit to Trostre Works, Tuesday, 7th October

The Steel Company of Wales Ltd have kindly issued an open invitation to the Members of the Institute and their Ladies to visit their Works at Trostre on **Tuesday, 7th October,** whether they are taking part in the Institute's Meeting or not. Lunch and tea will be provided by the Company at Trostre.

Corrosion of Phosphate Coatings

A meeting organized by The Iron and Steel Institute in conjunction with the British Iron and Steel Research Association, to discuss papers on the corrosion of steel under phosphate coatings and protective finishes, will be held at the offices of The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, at 2.0 P.M. on **Tuesday, 28th October, 1952.** Mr. H. T. Shirley, Chairman of the Corrosion Committee of B.I.S.R.A., will be in the Chair.

The programme is as follows:

Joint Discussion on:

"*Phosphate Coatings as a Basis for Painting Steel,*" by the Phosphate Coatings (Drafting) Panel of the British Standards Institution (Jan., 1952). (To be presented by Dr. J. C. Hudson, Chairman of the Panel)

"*Corrosion by Retained Treatment Chemicals on Phosphated Steel Surfaces,*" by S. G. Clark and E. E. Longhurst (Jan., 1952)

"*Tentative Analytical Tests for Phosphate Coatings on Steel,*" by R. St. J. Preston, R. H. Settle, and J. B. L. Worthington (Jan., 1952)

Discussion on:

"*Second Report of the Methods of Testing (Corrosion)*

Sub-Committee." (July, 1952.) (To be presented by Dr. J. C. Hudson, Chairman of the Sub-Committee.)

A few reprints of the papers are available, at 1*s.* 0*d.* each for the paper by Preston, Settle, and Worthington, and at 5*s.* 0*d.* each for the other three papers. Requests, accompanied by a remittance, should be sent to the Secretary of The Iron and Steel Institute.

The meeting will be open to all interested in the matters under discussion. There will be no charge for admission, but tickets will be required, and these are obtainable from the Secretary of The Iron and Steel Institute.

Autumn General Meeting, 1952

The **Autumn General Meeting** will be held in London on Wednesday and Thursday, **26th and 27th November, 1952.**

Symposium on High-Temperature Steels and Alloys for Gas Turbines

In February, 1951, a Symposium on " High-Temperature Steels and Alloys for Gas Turbines " was held at the Institution of Civil Engineers. A complete report upon it, containing thirty-six papers and the subsequent discussion, has now been published by the Institute. The Fifth Hatfield Memorial Lecture, on " Some Turbine Problems in the Development of the Whittle Engine," given by Sir Frank Whittle, is also included.

The object of the Symposium was to present a comprehensive picture of the work carried out in this field by British metallurgists during the last ten years. Thus, much original work is presented together with summaries of previously published work, and general trends for the future are indicated.

The papers are grouped under subject headings. They cover the main difficulties of the gas-turbine designer and user ; the effects of the use of high-alloy steels on the performance of the turbine ; scaling and fatigue of steels at elevated temperatures ; and such problems as those associated with the machining of heat-resisting and creep-resisting steels and alloys. Special casting and welding techniques are described, and information of particular assistance to designers, planning engineers and workshop personnel is given. Discussion on the properties and development of special steels and blade materials includes a detailed study of the 3% Cr-Mo-W-V alloy steel and a review of the potentialities of ceramics for use in gas turbines.

In the Hatfield Memorial Lecture, Sir Frank Whittle describes the early development of the Whittle jet engine, with emphasis on the turbine problems encountered.

The Report, No. 43 in the Special Report Series, is fully illustrated with diagrams and photographs, and is bound in cloth with stiff board covers ; it can be obtained from the Offices of the Institute at £3. 3*s.* 0*d.* per copy, post free.

NEWS OF MEMBERS

▶ Mr. D. V. AYRES has been awarded the degree of B.Sc. (Hons. Met.) of the University of Durham, and is now Technical Assistant with Messrs. Henry Wiggin and Co., Ltd., Birmingham.

▶ Mr. G. W. BROWN, Chief Metallurgist at Douglas (Kingswood) Ltd., Bristol, has been appointed Hon. Secretary of the Bristol and West of England Branch of the Institute of British Foundrymen.

▶ Mr. H. H. BURTON, C.B.E., of English Steel Corporation Ltd., has been elected a Vice-President of B.I.S.R.A., in succession to Prof. Sir Alfred Egerton, F.R.S.

▶ Mr. J. H. COOK is now employed at the Brown-Firth Research Laboratories, Sheffield.

▶ Mr. T. DENNISON has left B.I.S.R.A. to join the technical staff of the British Iron and Steel Federation.

▶ Mr. H. E. DIETRICH has left Vereeniging to take up an appointment with Pan African Industries, Johannesburg, S. Africa.

▶ Mr. R. B. GIBBON has been awarded the degree of B.Sc. of the University of Durham.

▶ Mr. R. H. HICKLEY has received the degree of Ph.D. from Sheffield University, and has also been awarded the Brunton Medal for 1952. He is now with the Mond Nickel Company, Ltd., Birmingham.

▶ Mr. F. HOUGHTON, Director of Messrs. Pickford, Holland and Co., Ltd., Sheffield, has been elected President of the Refractories Association of Great Britain for the year 1952–53.

▶ Mr. G. H. JACKSON has left the Amalgamated Dental Co., Ltd., to rejoin Messrs. C.A.V. Ltd., Acton, as Chief Metallurgist.

▶ Mr. W. LUMB has been awarded the degree of B.Sc. (Hons. Met.) of Sheffield University, and has now commenced his National Service in the R.E.M.E.

▶ Mr. J. MARWAHA has been appointed Assistant Works Manager (Under Training) at the Metal and Steel Factory of the Indian Ordnance Services, at Ishapur, W. Bengal.

▶ Mr. H. MEIER has left George Fischer Ltd., of Schaffhausen, to join the Foundry Department of Sulzer Brothers Ltd., Winterthur, Switzerland.

▶ Mr. P. T. MOORE has been awarded the degree of Ph.D. of the University of London, and has also been awarded the D.I.C. He has taken up an appointment as Technical Officer (Metallurgical) with Imperial Chemical Industries, Ltd., Billingham, Co. Durham.

▶ Mr. R. L. MORTON has left Messrs. Babcock and Wilcox Ltd., Renfrew, to take up the appointment of Chief Metallurgist with the Consolidated Pneumatic Tool Co., Ltd., at their Tullos Factory, Aberdeen.

▶ Mr. S. M. NAIM has left Precision Metalsmiths, Inc., Cleveland, U.S.A., to return to India as metallurgist with The Tata Iron and Steel Co., Ltd., Jamshedpur.

▶ Mr. B. D. PALIWAL has been awarded the degree of B.Sc. (Met. Eng.) from Banaras Hindu University. He is at present serving with Indian Malleable Castings Ltd. as a foundry foreman.

▶ Mr. J. R. M. RICHARDS has left Stewarts and Lloyds, Ltd., to take up an appointment with Guest, Keen and Baldwins, Ltd., East Moors, Cardiff.

▶ Mr. A. D. SARKAR has left Coltness Iron Works Ltd., and is now at the Royal Technical College, Glasgow, to take the Metallurgy degree course of Glasgow University.

▶ Mr. H. C. SHARMA has left Coventry Heat Treatments, Ltd., to continue his practical training with Ruhrstahl Aktiengesellschaft, Hattingen, W. Germany.

▶ Mr. ERIC SHAW, Sales Director of the Oughtibridge Silica Firebrick Co., Ltd., and Director of Monolithic Dolomite Ltd., Streetley, has been elected a member of the Council of the Refractories Association of Great Britain.

▶ Mr. P. SPEAR, of Messrs. Rubery, Owen and Co., Ltd., Darlaston, South Staffs., has been appointed Director of Research at the Research and Development Department of the Company.

▶ Mr. VERNON THOMAS has been awarded a 1st class honours degree in metallurgy at the University of Wales, and has taken up an appointment in the Research Laboratories of the General Electric Co., Ltd., Wembley.

▶ Mr. C. J. THWAITES has left the British Non-Ferrous Metals Research Association to take up an appointment in the Tinplate Section of the Tin Research Institute, Perivale, Middlesex.

▶ Mr. C. W. TUCK has taken up an appointment with Modern Hardmetals, Ltd., Sheffield.

▶ Mr. D. M. WAINHOUSE has been awarded the degree of B.Sc. of the University of Leeds.

▶ Mr. P. WATSON has left I.C.I., Ltd., Manchester, to take up an appointment as engineer in the Heavy Research Plant Section of the Ministry of Works, London.

▶ Mr. C. G. WILLIAMS has left Norton Motors, Ltd., Birmingham, to take up an appointment as Heat Treatment Superintendent with Garringtons, Ltd., Bromsgrove.

Obituary

Mr. L. DE BROUCKERE, on 4th June, 1951.

Mr. J. CHISHOLM, of Birmingham, in September, 1951.

SIR HENRY C. ELSE, of Sheffield, on 20th October, 1951.

Sir WILLIAM T. GRIFFITHS, formerly Chairman and Managing Director of the Mond Nickel Co., Ltd., on 30th July, 1952.

Mr. C. J. GRIST, of Brewood, Staffs., in February, 1952.

Mr. P. D. RIDGE-BEEDLE, Chairman and Governing Director of Ridge-Beedle and Co., Ltd., Glasgow, on 8th May, 1952.

Mr. JAMES SILLAVAN, Director of Leigh and Sillavan, Ltd., Manchester, on 8th June, 1952.

Dr. G. B. WATERHOUSE, Emeritus Professor of Metallurgy at the Massachusetts Institute of Technology, U.S.A., on 10th May, 1952.

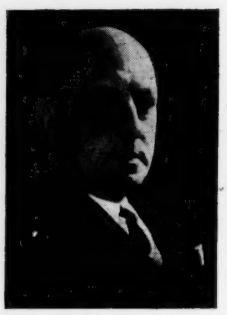
Mr. F. WELLER, of Sudborough, Northants., on 25th May, 1952.

CONTRIBUTORS TO THE JOURNAL

R. N. Parkins, B.Sc., Ph.D., L.I.M.—Lecturer in Metallurgy, King's College, University of Durham, Newcastle-on-Tyne. Dr. Parkins was educated at King James I Grammar School, Bishop Auckland, and at King's College, University of Durham. He graduated with First Class Honours in Metallurgy, and was awarded the Saville Shaw Memorial Medal of the Society of Chemical Industry in 1947. Dr. Parkins took up his present appointment in that year, and for his subsequent work on the stress-corrosion of mild steels he was awarded the degree of Ph.D.

J. W. Menter, M.A., Ph.D., A.Inst.P.—I.C.I. Fellow at the Laboratory for Research on the Physics and Chemistry of Surfaces, Department of Physical Chemistry, University of Cambridge. Dr. Menter was educated at the Dover County School and at Peterhouse, Cambridge, where he was a scholar of his college; he graduated in Physics. During the war, he worked as an Experimental Officer at H.M. Anti-Submarine Establishment. Returning to Cambridge in 1945, Dr. Menter has since worked in the Department of Physical Chemistry, first as a research student and latterly as an I.C.I. Fellow. He has been interested mainly in the application of electron diffraction and microscopy to the study of surface phenomena.

J. W. Menter



M. Langen

R. T. Eddison, M.A.—Head of Operational Research, British Iron and Steel Research Association. Mr. Eddison was born in 1916, and was a scholar of Charterhouse and of Pembroke College, Cambridge, where he graduated in Natural Sciences. He served in the Royal Artillery from 1939 to 1945, and then joined the statistical department of Rothamsted Experimental Station. He took up his present appointment in 1948. Mr. Eddison is also a joint Editor of the *Operational Research Quarterly*.

Mathias Langen, A.M.I.Mech.E.—Director of the Loewy Engineering Company, Ltd. Mr. Langen has been with the Loewy Engineering Company since 1937, and was appointed to the Board of Directors in 1948, in which position he is responsible for the activities of the Rolling Mill Department. Mr. Langen's entire career has been spent in many countries on the layout and design of hot and cold mills for ferrous and non-ferrous metals.

G. R. Wilson, B.Sc.—Chief Engineer, Metal Industries Division, English Electrical Company, Ltd. Mr. Wilson graduated from King's College, London, with the degree of B.Sc. (Hons. Eng.) in 1939. Since 1936 he had been a student apprentice with English Electrical Company, and this training continued until 1941, when he joined the Rectifier Section. Subsequently Mr. Wilson worked on the application of electric drives to industry, mainly of the steelworks and non-ferrous type, in the Special Engineering Section. The Metal Industries Division, where he is now Chief Engineer, has recently been formed from this Section.

IRON AND STEEL ENGINEERS GROUP

The **Nineteenth Meeting** of the Group will be held in London on **Thursday, 30th October, 1952.** Two papers will be presented for discussion : "Electric Drives for Continuous Hot Mills," by G. R. Wilson (*this issue*, pp. 215–225), and "A New Continuous Hot Mill for Strips up to 24 in. Wide," by M. Langen (*this issue*, pp. 203–214).

The **Twentieth Meeting** of the Group will be held in London on **Thursday, 11th December, 1952.** At the Morning Session, three papers will be presented for discussion : "Experiences with the Escher Metallic Recuperator on High-Temperature Furnaces," by H. Escher (Sept. 1951, pp 39–46) ; "Trials of an Experimental Austeel-Escher Metallic Recuperator," by J. B. Davis, W. Ernest, and H. Kay (Jan. 1951, pp. 66–70) ; and "Heat Recovery in Industrial Furnaces," by A. Clift and C. Knight (Nov. 1952, *in the press*).

At the Afternoon Session, discussion will be devoted to the paper by D. F. Marshall on "Fuel Applications in Open-Hearth Furnaces" (*in the press*).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Corrosion Committee—Conference at Ashorne Hill

The activities of the Corrosion Committee are such that there are now nearly 70 members included in the Main Committee, Sub-Committees, and Panels. Much of the work is of a specialized or environmental nature, requiring advice and assistance from those with specialized knowledge of the particular fields studied, and an obvious concentration of effort in specific directions. It was felt by the Main Committee that it would be useful

and stimulating to the work as a whole if a Conference could be arranged at which all concerned with these investigations could meet. Such an occasion would provide for interchange of ideas and information between the various groups, as well as giving much greater opportunities for informal discussions than are available at the ordinary meetings or public conferences.

The Conference will be held at Ashorne Hill, Leamington Spa, from **27th to 29th January, 1953,** and the cost will be approximately 32*s.* 6*d.* per day. Application forms will be dispatched at a later date. The potential value of this Conference can be realized only if a large proportion of members is present, and it is hoped that all who can possibly attend will do so.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

A Joint Meeting of the Swansea and District Metallurgical Society and The Iron and Steel Institute will be held at the Central Library, Swansea, on **Wednesday, 12th November, 1952,** at 6.30 P.M. Mr. H. N. Bowen, President of the Swansea and District Metallurgical Society, will be in the Chair.

The paper on " The Variation in Electrical Properties of Silicon-Iron Transformer Sheets," by S. Rushton and D. R. G. Davies (*J. Iron Steel Inst.*, 1951, vol. 167, pp. 247–261), will be presented by the authors for discussion.

INSTITUTE OF METALS

Symposium on Properties of Metallic Surfaces

A symposium on " Properties of Metallic Surfaces," arranged by the Institute of Metals, will be held in the Lecture Theatre of the Royal Institution, Albemarle Street, London, W.1, on **Wednesday, 19th November, 1952,** from 9.45 A.M. to 5.0 P.M.

The following papers will be discussed :

Morning Session

Joint Discussion on :

" *Specialized Microscopical Techniques in Metallurgy,*" by S. Tolansky

" *Radio-isotopes in the Study of Metal Surface Reactions in Solutions,*" by M. T. Simnad

" *The Crystalline Character of Abraded Surfaces,*" by P. Gay and P. B. Hirsch

" *Diffusion Coatings,*" by D. M. Dovey, I. Jenkins, and K. C. Randle

" *The Nature and Properties of the Anodic Film on Aluminium and its Alloys,*" by H. W. L. Phillips

" *Chemical Behaviour as Influenced by Surface Condition,*" by U. R. Evans

" *The Effect of Method of Preparation on the High-Frequency Surface Resistance of Metals,*" by R. G. Chambers and A. B. Pippard

Afternoon Session

Joint Discussion on :

" *The Influence of Machining and Grinding Methods on the Mechanical and Physical Condition of Metal Surfaces,*" by P. Spear, I. R. Robinson, and K. J. B. Wolfe

" *The Effect of Lubrication and Nature of Superficial Layer After Prolonged Periods of Running,*" by F. T. Barwell

" *The Effect of Surface Conditions on the Mechanical Properties of Metals, Mainly Single Crystals,*" by E. N. da C. Andrade

" *The Effect of Surface Conditions on the Strength of Brittle Materials,*" by C. Gurney

" *The Influence of Surface Condition on the Fatigue Strength of Steel,*" by R. J. Love

" *The Influence of Surface Films on the Friction and Deformation of Surfaces,*" by F. P. Bowden and D. Tabor

Non-members of the Institute who wish to register for the meeting should apply to the Secretary, The Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

NEWS OF SCIENCE AND INDUSTRY

The Australian Institute of Metals

The Melbourne Branch of The Australian Institute of Metals is organizing a symposium on "The Theory and Practices of Wire Drawing," which will be held in October, 1953. The Institute would welcome papers of approximately 3000–4000 words for inclusion in the symposium.

Symposium on Industrial Failure of Engineering Metals and Alloys

A symposium on " Industrial Failure of Engineering Metals and Alloys " is to be held at the National Metallurgical Laboratory, Jamshedpur, India. The symposium will be broadly divided into two main parts : (i) the theoretical aspect of industrial failures, and (ii) a study of actual service failures, including a probe into their causes and possible remedial measures. Technical papers on these subjects would be welcomed, and advance copies should be forwarded to the National Metallurgical Laboratory before 31st October, 1952. Equipment for the projection of slides and drawings will be available.

The Institute of Fuel

A special study of ash and clinker in industry is being undertaken by the Institute of Fuel during the 1952–53 Session, with a view to encouraging the more economical utilization of the national fuel resources. The Opening Conference will be held on **28th and 29th October, 1952,** at The Institution of Mechanical Engineers, Storey's Gate, London, S.W.1.

International Tables for X-Ray Crystallography

Volume I (Symmetry Groups) of the Internationa Tables for X-Ray Crystallography, published for the International Union of Crystallography, is now ready. The text and tables (in English) have been planned to be of the maximum practical usefulness in the determination of crystal structures and in allied problems, but their value for teaching purposes has also been kept in mind. Volume I contains 558 pp. and 237 figures, with a dictionary in English, French, German, Russian, and Spanish; it is bound in cloth and costs £5 5*s.* 0*d.* inclusive of postage and packing. Members of The Iron and Steel Institute may obtain one copy, for their personal use only, at the subscription rate of £3 post free, by using a special order form available, with the prospectus, from the Kynoch Press, Witton, Birmingham, England.

Volumes II and III, which are in preparation and will be sold separately, will cover Mathematical, Physical, and Chemical Tables used in X-Ray Crystallography.

Acta Crystallographica

The subscription per annual volume of *Acta Crystallographica,* an international journal which is of general crystallographic interest and reports on the activities of the International Union of Crystallography, is 100 Danish crowns, post free. Arrangements have, however, been made for bona fide crystallographers in countries adhering to the Union to obtain the journal for their

private use at the reduced price of 60 Danish crowns or $9, post free. Such subscription can be accepted only if placed direct with Messrs. Ejnar Munksgaard Ltd., Nörregade 6, Copenhagen, or with the American Institute of Physics, 57 East 55th Street, New York 22, U.S.A., accompanied by a declaration that the journal will be solely for the personal use of the subscriber.

The Steel Company of Wales, Ltd.

The new No. 3 blast-furnace at the Margam Works of the Company has been 'blown-in.' The furnace, which has a hearth diameter of 25 ft. 9 in., is the second to be erected as part of the development project which has been carried out at the Works since 1947. The furnace stands on a site formerly occupied by a 16-ft. furnace, which was completely dismantled before erection of the new furnace could begin. Erection of the steelwork for the new furnace began in July 1951, and bricking in September 1951. Altogether, 2000 tons of steelwork and more than ¼ million refractory bricks have been used. The furnace is capable of producing 1000 tons of iron per day, given suitable iron ore, and its completion marks another important step in the reconstruction programme of the Margam Works.

Britain's Largest Steel Ingot

English Steel Corporation Ltd. have recently cast at their River Don works the largest steel ingot made in Britain. It is 26 ft. long and 9 ft. across the largest octagonal section, and used 270 tons of special steel from four acid open-hearth Siemens furnaces.

The ingot will be forged under a 7000-ton electric-hydraulic press into a one-piece hollow forged boiler drum, 42 ft. long, 6 ft. 2¼ in. outside diameter and 5 ft. 6 in. bore, ordered for a new power station of the British Electricity Authority.

Structure Reports for 1947–1948

Structure Reports, an international undertaking sponsored by the International Union of Crystallography, is a continuation of the pre-war publication *Strukturbericht*, the last issue of which was vol. VII for 1939. The first volume (11) of Structure Reports is for 1947–48; vols. 8–10 for 1940–46, and vol. 12 for 1949, are in course of preparation. Volume 11 (779 pp.) can be obtained from N.V. A. Oosthoek's Uitgevers MIJ., Domstraat 1–3, Utrecht, Holland, at 55 Dutch florins per copy, post free.

New Sales Company for Steel Products

Richard Thomas and Baldwins Ltd. and The Steel Company of Wales Ltd. jointly announce the formation of "RTSC Home Sales Limited." The first Directors of the company will be Mr. H. F. Spencer, Assistant Managing Director of Richard Thomas and Baldwins Ltd., and Mr. E. Julian Pode, Managing Director of The Steel Company of Wales Ltd., who are Directors of RTSC Exports Limited. The Company will not become active until the new year, and customers are requested to continue their present contracts with the individual companies until advised to the contrary.

The registered office of the Company will be at 47 Park Street, London, W.1.

Wild Barfield Electric Furnaces, Ltd.

Messrs. Wild Barfield Electric Furnaces Ltd., in conjunction with their associates, Messrs. G. W. B. Electric Furnaces Ltd., have established an office in Scotland, to be under the control of their representative Mr. D. McDermott. The address of the office is 131 West Regent Street, Glasgow C.2. (Tel. Douglas 8839.)

Industrial Publications Received

▶ Amberlite Insulating Bricks for "Hot-Face" Insulation—General Refractories Ltd.

▶ The Twin-Arc Welding Process—Brochure No. T.C. 854, The Quasi-Arc Company Ltd.

▶ Laboratory Super-Centrifuges—Bulletin No. 152, Sharples Centrifuges Ltd.

▶ Supramor Electro-Magnetic Flaw Detection Ink—Leaflet No. 4, Manchester Oil Refinery Ltd.

▶ Laboratory Specialities—Catalogue No. 16B-S, Griffin and Tatlock Ltd.

▶ Quality Controlled, Special-Purpose Steels—Parker Foundry (1929) Ltd.

▶ The Summerson Book of Railway Sidings—Thomas Summerson and Sons, Ltd.

▶ The Fyrite (for CO_2 measurement in flues)—The Shandon Scientific Company, Ltd.

DIARY

2nd Oct.—LEEDS METALLURGICAL SOCIETY—Presidential Address, by Dr. N. J. Petch—Leeds.

7th–9th Oct.—IRON AND STEEL INSTITUTE—Special Meeting—Swansea.

15th Oct.—NORTH WALES METALLURGICAL SOCIETY—"*Some Aspects of Blast-Furnace Practice*," by G. H. Johnson—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 P.M.

20th–24th Oct.—AMERICAN SOCIETY FOR METALS—National Metal Congress and Exposition—Philadelphia.

20th–25th Oct.—SOCIÉTÉ FRANÇAISE DE MÉTALLURGIE—Annual Autumn Metallurgical Meeting—Paris.

27th Oct.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY (Joint Meeting with the Institute of Clay Technology)—"*Refractories in the Steel Industry*," by G. R. Rigby—Whitehead Institute, Cardiff Road, Newport, 7.0 P.M.

28th–29th Oct.—INSTITUTE OF FUEL—A Special Study of Ash and Clinker in Industry—Opening Conference—Lecture Hall, The Institution of Mechanical Engineers, Storey's Gate, London, S.W.1.

30th Oct.—IRON AND STEEL ENGINEERS GROUP—Discussion on Continuous Hot Mills—London.

TRANSLATION SERVICE

(The previous announcement was made in the September, 1952, issue of the *Journal*, p. 100).

TRANSLATIONS AVAILABLE

No. 453 (German). E. KUNZE: "Protective Gases for the Heat-Treatment of Steels." (*Stahl und Eisen*, 1952, vol. 72, May 8, pp. 561–569).

No. 454 (German). E. SCHEIL and R. SCHNELL: "The Deformability of Slag Inclusions in Steel, and its Significance in the Assessment of Forgings." (*Stahl und Eisen*, 1952, vol. 72, June 5, pp. 683–687).

TRANSLATIONS IN COURSE OF PREPARATION

(German). O. J. STEBEL: "Design and Operation of Modern Soaking Pits." (*Stahl und Eisen*, 1952, vol. 72, Apr. 24, pp. 466–474).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUESTS—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Stratigraphy and Bentonitic Shale Deposits of Kekerangu and Blue Slip, Marlborough. E. O. Macpherson. (*New Zealand J. Sci. Technol.*, 1952, **33**, Jan., 258–286).

Investigation of Two Iron Deposits in Älvdalen. P. Enghag. (*Blad Berg. Vänner*, 1951, No. 1, 229–237). [In Swedish].

Ores of Alloying Metals—Occurrence, Mining, and Concentration. L. E. Berglund. (*Tekn. Tidsskr.*, 1952, **82**, May 13, 451–456). [In Swedish]. This is a review of the most important world sources (excluding Russia) of cobalt, chromium, manganese, molybdenum, vanadium, tungsten, wolfram, and titanium, with up-to-date production figures. Mining methods and concentration processes are described with especial reference to tungsten.—G. G. K.

ORES—MINING AND TREATMENT

Characteristics and Operation of Coal and Ore Bridges. E. L. Blankenbeker. (*Iron Steel Eng.*, 1952, **29**, May, 102–108). The author examines the more important electrical features of modern coal and ore bridges. Bucket-hoist, bridge, and trolley drives are studied and performance curves are given for the motors.—M. D. J. B.

Manganese: Sources and Beneficiation. (*J. Met.*, 1952, **4**, Apr., 377). This article briefly discusses the sources of manganese ore imported by the American steel industry, and outlines methods of beneficiation of domestic ores.—G. F.

Extraction, Refining and Use of Mica and Nepheline and Beneficiation of Manganese Ores. A. O. Poulsen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1952, **12**, Feb., 31–36). [In English]. The paper presents details of American mica extraction, and flotation processes and the Bureau of Mines method of recovering 80% of the manganese in open-hearth slags is commented on.—G. G. K.

Drying of Ironstone. R. C. Walthew. (*Ceramics*, 1951, **3**, Dec., 513–518). The drying of Northamptonshire ores by static and rotary dryers at the Appleby-Frodingham Steel Co. is described and the results from each type of drier are discussed. The moisture content of the dried ore from the static drier was substantially lower than from the rotary one and the fuel consumption of the static plant was much higher than that of the rotary plant.—E. C. S.

Internal Kinetics of Ball Mills. R. Liebold. (*Technik*, 1952, **7**, Mar., 113–118). The author attempts to determine the pressure between the pulverizing elements of ball mills by calculation in a manner which will avoid differences between measured and calculated pressures. He employs the theory of vibration.—J. G. W.

Progress in Hammer-Mill Crushing in the U.S.A. C. Mittag. (*Z.V.d.I.*, 1952, **94**, May 1, 365–367). Single and double roll crushers of recent American manufacture are described and data on size, performance, and costs are given.—J. G. W.

Air Bubble and Flotation Process. P. Siedler. (*Z. Erz u. Metall.*, 1952, **5**, Feb., 49–54). A survey is made of physical principles and the theoretical background underlying the process of froth flotation. The rôles played by the carrier gas and by surface forces are discussed. Theories concerning the mechanism of collection are described and contrasted. Further investigations are suggested concerning gas solubility, visual study of the collection process, and high-frequency froth flotation.—E. C.

Problems of Magnetizing Roasting of Iron Ores in a Rotary Furnace. W. Wahlbrecker. (*Z. Erz u. Metall.*, 1952, **5**, Feb., 54–61). Improvements are suggested concerning operation and construction of the Lurgi kiln. Optimum lump size of ores is discussed, and an optimum roasting temperature of 500–550° C. was determined experimentally. The time required for reduction is related to lump size, and indirect water cooling of the ore in the end portion of the kiln is suggested. The capacity of large kilns is improved by means of spiral blades which equalize the load distribution and improve gas penetration.—E. C.

The Lay-Out and Operation of a G.H.H.-A.I.B. Sinter Plant. R. Hahn. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1942, **9**, Dec., No. 10, 206–212). The usual present-day sintering methods are first described. A thorough description follows of the A.I.B. (Allmänna Ingeniörsbyrån) and the G.H.H. (Gutehoffnungshütte) sintering methods and the two are compared. Diagrams indicate the layout of the plants; their mode of operation is fully described. Finally, experimental results from the plants are given.

Improvement in Quality of Sinter and in Sinter Plant Production. S. L. Koptevskii and A. N. Machkovskii. (*Metalurg*, 1940, **15**, 9, 11–15). Desirable sinter qualities and methods of testing are discussed. From the results of sintering experiments it is concluded that the mechanical properties of sinter can be improved by better mixing of the charge, and the sintering time can be reduced by the addition of either manganese ore tailings, or soda and sodium chloride.—V. G.

FUEL—PREPARATION, PROPERTIES, AND USES

Fuel Technology and Civilisation. G. E. Foxwell. (*Gas World*, 1952, **135**, May 10, 464–467; May 17, 504–506; May 24, 524–527). The very early history of fuel technology is

described, and the early blast-furnaces and first efforts at coke-making are mentioned. In the second section, the developments in the use of steam are traced, and early theories on heat are quoted. Finally, fuel, energy, and the future are discussed, with particular reference to the fuel shortage in Great Britain.—T. E. D.

Energy from Fossil Fuels. M. K. Hubbert. (Annual Report of the Board of Regents of the Smithsonian Institution, 1950, 255–272). The world production of energy from coal and petroleum in the past, present, and future is discussed in relation to population and technical developments.—R. A. R.

Recent Aspects of the Chemical Value of Coal. (*Rev. Univ. Min.*, 1952, Series 9, **8**, Apr., 94–107). A number of processes using coal are reviewed including the manufacture of petroleum-type products by the Fischer-Tropsch synthesis. The use of methane from coal mines is discussed together with the production of acetylene from methane. A short account of the theories of the combustion of carbon is given.—B. G. B.

The Influence of Boiler Design and Operating Conditions on Steam Contamination. P. M. Brister, F. G. Raynor, and E. A. Pirsh. (Amer. Soc. Mech. Eng.: *Blast Furn. Steel Plant*, 1952, **40**, Mar., 338–344; Apr., 436–442).

Thermal Service in Steelworks. M. Collignon. (*Rev. Univ. Min.*, 1952, Series 9, **8**, Apr., 107–113). If efficient use is to be made of the large amounts of energy which are used in steelworks, accurate control and measurement at the various consuming and producing points are essential. The author outlines the duties of a 'thermal service' whose task is to see that the most efficient use is being made of the energy.

Coal Preparation in South Wales. W. H. Griffiths. (*Min. Elect. Mech. Eng.*, 1952, **32**, Mar., 271–281). Coal preparation in the National Coal Board Southwestern Division is reviewed. Types of coal mined range from low-volatile anthracite of high rank to high-volatile coals of low rank, and coking and gas coals. Mechanical cleaners are mainly of the Baum type, but Rheolaveur washers, Blackett Barrel washers, dense-medium washers, and dry cleaners are also used.—T. E. D.

Report of Tests Carried out on The Swing Hammer Pulverizer. C. E. Bird. (*J. Chem. Met. Min. Soc. S. Africa*, 1951, **52**, Nov., 109–117). The paper describes a series of experiments carried out on a swing hammer pulverizer for coal. A full description is given of the machine, and the variables affecting its performance are noted.—D. H.

Practical Results in the Selection and Mixing of Coal and Improvement of the Coke in High Temperature Carbonization. F. L. Kuhlwein and C. Abramski. (*Glückauf*, 1939, **75**, Nov. 4, 865–874; Nov. 11, 881–890). From a large number of experimental results, it was established that, with coke–coal mixtures from coals with completely different qualities from that of gas coal, practically the same success with coking could be achieved. By applying the results from the research described in this paper to other coal districts it should be possible to produce better coal than hitherto. Coals from various parts of Germany and some from England were used in this work.

Investigations of the Plasticity of Bituminous Coals. K. Hoehne. (*Glückauf*, 1939, **75**, Dec., 941–945). A Gieseler's plastometer was used to measure the plasticity of a large number of coals, and a relationship established between the operative plastic zone and the strength of the coke. The plasticity is thus a valuable medium for judging the properties of coking coals, since such a determination only takes about 1 hr. to carry out.—R. J. W.

The Position of Underground Gasification in Russia. W. Gumz. (*Glückauf*, 1940, **76**, Apr. 13, 210–213). A short account is given of trials at five places in Russia, and of one industrial-scale plant at Gorlowka where the underground gasification of bituminous and brown coal has been attempted, in some cases with success.—R. A. R.

Fuel and Metal. R. J. Sarjant. (Inst. British Foundrymen: *Foundry Trade J.*, 1952, **92**, June 12, 619–628: *Engineering*, 1952, **173**, June 13, 759–762). The author considers the characteristics required of a coke for metal extraction and suggests that the prime importance of the reactivity has been underestimated. He refers also to current research, dealing with the effects of temperature, heat content of the coal, gas velocity, preheating the blast, and blast humidity.

Clean Producer Gas from Bituminous Coal. (*Indust. Gas*, 1951, **15**, Nov., 56–60). Brief details are given of a new process for the cleaning of producer gas obtained from bituminous coal. The products of this process are, clean gas, water-free pitch and light oil, and clear hot water. The layout of the plant is compact and a high efficiency is obtained.—D. H.

TEMPERATURE MEASUREMENT AND CONTROL

The Spectrum-Line Reversal Method of Measuring Flame Temperature. A. G. Gaydon and H. G. Wolfhard. (*Proc. Phys. Soc.*, 1952, **65A**, Jan. 1, 19–24). Processes of electronic excitation are briefly discussed. If there is lack of equilibrium, the reversal temperature may be closer to the effective vibrational temperature of the surrounding molecules than to the mean translational temperature. The lack of radioactive equilibrium in all flames will cause measured temperatures to be too low; for a flame with air at 2000° K. using sodium, the error will be between 3·3° and 1·6° at 1 atm., and more at lower pressures. For hot flames, above 2700° K., the OH band may be used for reversal measurements; it has some advantages over the use of sodium.—C. J. B. F.

The Temperature Impulse for the Control of Furnaces. C. Sieber. (*Metallwirtschaft*, 1943, **22**, Aug. 20, 405–411). A feedback circuit for controlling the temperature of a furnace is shown. In this, some type of measuring probe is made to control the rate at which impulses of heat are supplied to the furnace. The effect of temperature lag in the probe and the manner in which a temperature is converted into other units are described. Mechanical thermometers such as metal and liquid expansion, steam pressure thermometers, thermocouples, resistance thermometers, and radiation pyrometers are described.—R. J. W.

Temperature Control Applications. (*Overseas Eng.*, 1952, **25**, June, 392–394). By the adoption of a common plug-in type of chassis, together with unit construction, the standardization of a large number of different instruments can be obtained. 'On-off,' proportional, and programme type electronic temperature controllers, operating from a thermocouple or resistance thermometer, which incorporate this standard chassis, are described.—B. G. B.

Industrial Measurement of Elevated Temperatures in Metal, Salt, and Slag Melts. H. v. Zeppelin (*Giesserei*, 1952, **39**, June 12, 287–289). The author describes a graphite-sheathed immersion thermocouple. The thermocouple is placed in a nickel tube which is attacked by the metal, thus protecting the thermocouple. It is suitable for measurement up to 1250° C., and for continuous use.—J. G. W.

Automatic Control of Gas-Fired Heat-Treatment Furnaces. L. Walter. (*Machinery*, 1952, **80**, Feb. 14, 284–287). Apparatus for the efficient control of the temperature of a large gas-fired heat-treatment furnace is described.—R. A. R.

REFRACTORY MATERIALS

Refractory Aspects of Some Egyptian Clays. G. M. Gad. (*Refract. J.*, 1952, **28**, Apr., 162–168). Five Egyptian clays and sands were investigated to determine their suitability for making refractory bricks. Certain mixtures were suitable for making semi-silica bricks, and semi-insulating bricks.

Differential Thermal Analysis of Gangue Minerals in Chrome Ores. H. Heystek. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Apr., 133–138).

Sillimanite Refractories. W. L. German. (*Ceramics*, 1952, **4**, May, 104–110). The composition, properties, production, and uses of sillimanite refractories are discussed.—E. C. S.

Carbon—A Refractory and Material of Construction. (*Ceramics*, 1952, **4**, Mar., 7–15). When heated above 350° C., carbon is subject to oxidation. Its use at elevated temperatures is therefore restricted to processes where reducing conditions prevail, as in blast-furnaces making iron. For this application its advantages over fireclay are claimed to be: (*a*) Resistance to chemical attack; (*b*) low thermal conductivity; (*c*) high resistance to thermal shock, (*d*) refractoriness, (*e*) thermal conductivity, (*f*) good strength at high temperatures, and (*g*) it is not wetted by molten slag or iron.—E. C. S.

Boron Nitride—An Unusual Refractory. G. R. Finlay and G. H. Fetterley. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Apr., 141–143). A procedure for producing boron nitride has been developed. The chemical, physical, and electrical properties are tabulated. Methods of analysis are described and the product is compared with other materials on the market.

Some Physical Properties of Eight Refractory Oxides and Carbides. J. J. Gangler. (*Ceramics*, 1951, **3**, Aug., 324–327). Data are presented on the properties of the following materials with a view to the possibility of using them in gas turbines:

Beryllium oxide; magnesium oxide; the carbides of titanium, zirconium, and boron; 85% silicon carbide plus 15% boron carbide; zircon; and stabilized zirconia.—R. A. R.

Laboratory Control in Firebrick Manufacture. W. P. Howells. (*Ceramics*, 1952, **4**, Mar., 21–26). An overall plan of control is suggested.—E. C. S.

Uniformity of Firebrick Quality. C. E. Moore. (Refractories Assoc. of Great Britain: *Refract. J.*, 1951, **27**, Dec., 517–523; 1952, **28**, Mar., 115–122). The need for a comprehensive research programme on firebrick uniformity is pointed out. The essentials of such a programme should be the determination of the relative importance of the various stages of manufacture.—E. C. S.

Notes on Production Methods in the Scottish Firebrick Industry. R. A. Bell and J. McWilliam. (Refractories Assoc. of Great Britain: *Refract. J.*, 1952, **28**, Mar., 97–114). The authors outline the salient features of present-day production methods, the ideas behind them, and the results obtained.

Size Variation of Blast Furnace Brick. K. A. Baab and H. M. Kraner. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Apr., 146–148). At the Bethlehem Steel Co., samples were obtained from three blast-furnace linings manufactured by two different producers. The length and thickness of the samples were measured to 0·001 in. and comparisons were made among the three linings and between the two producers to determine whether they were complying with the specifications. The need for more accurate control of dimensions was shown.

Limitations Imposed by Raw Materials on Firing Schedules. G. C. Robinson. (*J. Amer. Cer. Soc.*, 1952, **35**, Jan., 1–5). The raw material is the major factor in limiting the speed of firing when using tunnel kilns of small cross-section for firing refractories. The selection of materials that require short firing times can effect large reductions in firing time. For slow-firing materials, large reductions in firing time can be accomplished through control of the grog particle size distribution or through the addition of other clays or shales to the material.—E. C. S.

Tunnel Kilns for Firing Refractories. R. G. le Grip. (*Clay-craft*, 1952, **25**, Jan., 211–215; Feb., 268–274). The author discusses the design of large car tunnel kilns for firing refractories at medium and high temperatures.—E. C. S.

Electric Furnace for Ceramics and Refractories. D. M. Kazarnovskii. (*Zavodskaya Laboratoriya*, 1950, No. 2, 251–253). [In Russian]. An improved high-temperature furnace is described for which the following claims are made: (1) Reliability; (2) temperature attainable, 1550° C.; (3) good regulation and maintenance of temperature; and (4) maximum temperature difference in the chamber of $\pm$ 15° at 1300–1550° C.

Classification of Refractories. W. P. Howells. (*Ceramics*, 1952, **3**, Jan., 570–578). The article deals with the composition and performance of silica and siliceous bricks, firebricks, aluminous firebricks, and other refractories.—E. C. S.

Testing of Ceramic Materials in Tension. M. D. Burdick and R. F. Geller. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Apr., 143–144). This is a survey of testing methods for the determination of strength, and of changes in length at elevated temperatures under both prolonged and comparatively rapid applications of tensile stresses.—E. C. S.

A Protective Coating for Refractories. (*Ceramics*, 1951, **3**, Oct., 422–428). Details are given of 'Brickseal' coatings, which are marketed by XZIT (G.B.) Ltd., London. These are supplied in various grades suitable, it is claimed, for temperatures up to 1980° C. Both spalling and slag attack are reduced by the application of these coatings.—E. C. S.

An Automatic Apparatus for Testing Refractories Under Tensile and Compressive Loads at High Temperatures. (*J. Amer. Ceram. Soc.*, 1951, **34**, Nov., 348–353). Construction and operating details are given for an apparatus used for testing small refractory specimens under tensile or compressive loads up to 2200° C.—E. C. S.

The Elastic and Viscous Properties of Alumino-Silicate Refractories. B. A. Wiechula and A. L. Roberts. (*Trans. Brit. Cer. Soc.*, 1952, **51**, Mar., 173–197). Commercial products covering the whole range of the alumino-silicate series were investigated by means of X-ray analysis, differential thermal analysis, and microscopic examination of thin sections. Changes in the mechanical properties at temperatures up to 1400° C. were examined by torsion methods and values of the modulus of rigidity, ultimate shear strength, and the rates of 'flow' were determined. Results showed that there was no simple relation between Al_2O_3 content and the values at room temperature for modulus of rigidity or ultimate shear strength. The mineralogical constitution could, however, be correlated with these mechanical properties. With rise in temperature the rigidity increased to a maximum at about 700° C. This increase was substantial in the more siliceous materials and was due to the presence of free crystalline silica. After the development of plasticity (at 700–800° C.) rigidity decreased continuously and rapidly with rise in temperature.—E. C. S.

Röntgenographic Investigation of the Thermal Decomposition of Dolomite Crystals. R. A. W. Haul and H. Wilsdorf. (*Acta Crystallographica*, 1952, **5**, Mar., 250–255). The single-crystal method was used, and after complete decomposition to MgO and $CaCO_3$ the X-ray diagrams showed homogeneous powder patterns of MgO and single-crystal patterns of $CaCO_3$, which resulted from calcite crystallites orientated in the same way as the original dolomite. A reaction mechanism is suggested.—T. E. D.

Techniques for Growing and Mounting Small Single Crystals of Refractory Compounds. F. Ordway. (*J. Res. Nat. Bur. Stand.*, 1952, **48**, Feb., 152–158). An apparatus is described for growing single crystals in a small droplet of melt at temperatures up to 1600° C. The droplet, held by capillarity at the junction of a thermocouple, can be observed during the process through a binocular microscope. The heating is by means of a high-frequency current that can be separated by a filter from the thermocouple electromotive force, allowing the electromotive force to be measured continuously. The apparatus is therefore suitable also for determining melting points.—C. J. B. F.

Basic Refractories. C. S. Hedley. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Oct., 78–85). The composition and properties of some basic refractory materials are tabulated and the principal types used in foundry cupolas and ladles are reviewed. Stabilized dolomite brick and finely ground stabilized dolomite for patching are considered the most suitable materials for basic cupola linings. Similar bricks are suitable for lining basic ladles, but an effective method of patching has yet to be found.—B. G. B.

Some Refractories Problems in Steelworks. G. R. Bashforth. (Refractories Assoc. of Great Britain: *Refract. J.*, 1952, **28**, Apr., 142–156). Costs of refractories in relation to costs of producing steel are considered, and the repair of open-hearth furnaces, including the use of graphitized dolomite hearths, casting-pit refractories, and storage of refractories is discussed.—R. A. R.

Maintenance and Repairs to Refractory Brickwork. A. R. Myhill. (*Ceramics*, 1952, **4**, Mar., 30–36). Maintenance and repair of retort refractories may involve the following methods: (1) Spraying; (2) 'gunning,' (3) hot-patching with paddle; (4) welding; and (5) 'air-borne sealing.' These methods are described.—E. C. S.

A Survey of Zebra Roof Practice. C. E. Grigsby. (*J. Met.*, 1952, **4**, Feb., 132–139 : *Indust. Heating*, 1952, **19**, Apr., 707–716, 720–722; May, 848–860; July, 1250–1256). A zebra roof comprises rings of silica brick alternating with rings of basic brick in those areas subject to the greatest wear. The silica brick provides the roof's main strength but wears away more rapidly than the basic, thus leaving the latter protruding and affording a protection for the former. Production increases of from 2 to 10% have been reported since switching to this type of roof.

Experiences with Castable and Rammed Refractories. J. E. Deegan. (*Iron Steel Eng.*, 1952, **29**, May, .79). Applications of rammed refractory material to replace bricks and to lessen the work for the few skilled bricklayers are described.—R. A. R.

Application of Rammed Castable Refractories in Steel Mills. R. F. Fayles. (*Iron Steel Eng.*, 1952, **29**, May, 79–83). The successful applications of rammed refractories at the Lukens Steel Company's works include soaking-pit covers and reheating furnace roofs. Fantails and fantail noses in open-hearth furnaces are also reported.—R. A. R.

Experiences with Refractory Concrete. W. N. Horko. (*Iron Steel Eng.*, 1952, **29**, May, 83–84). Unsuccessful and successful uses of refractory concrete in a steel plant are described. The lining of reheating furnace doors with this material is recommended.—R. A. R.

Advantages of Rammed and Cast Refractories for Steel Plant Use. R. E. Wolfensperger. (*Iron Steel Eng.*, 1952, **29**, May, 84–85). The preparation and properties of fireclay ramming mixes are discussed. The initial strength is dependent upon the complete hydration of the water and the binder.—R. A. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Ensley's High Pressure Turbo-Blowers Increase Production, Decrease Coke Rates. J. J. Shannon. (*J. Met.*, 1952, **4**, Apr., 369–376). Since the installation of three high-pressure five-stage turbo-blowers at the blast-furnace plant of the Tennessee Coal, Iron and Railroad Co., Ensley, Alabama, iron production has increased by 430 short tons per day with a corresponding decrease in coke rate of 284 lb./short-ton of iron. The author analyses this improvement, and discusses the effects on production rate of conditioned ore burden, driving practice, and blast temperature and pressure.—G. F.

Blast Furnace Practice. C. E. Agnew. (*Steel*, 1951, **129**, Dec. 10, 102–109; Dec. 24, 66–72, Dec. 31, 62–65; 1952, **130**, Feb. 4, 90–91; Feb. 11, 82–84; Feb. 18, 112–120; Feb. 25, 88–93; Mar. 10, 118–120). This series of articles covers operating theories, thermal conditions, and generation, recovery, and use of heat. Thermal economy in blast-furnace operation depends on the proper distribution of heat in both volume and degree of concentration to the respective zones of the furnace where the respective divisions of work occur. The importance of gas flow through the stack and its relationship to the burden is stressed because of its importance in determining the heat economy of shaft operation. Thermal conditions in the bosh due to slag formation can exert a major influence on the fuel consumption and the productivity of the stack, and it is shown that an important relationship exists between constituents of the tapping slag and percentage of ash in the coke. Advantages to be gained by classifying slags by tetrahedrons are explained clearly. Uniform slag-constituent ratios indicate uniform chemical composition of burden components; uniform tetrahedron arrangement indicates the uniform movement of stock through the furnace. An explanation is given to show why Gruner's theory of the carbon solution loss reaction cannot be fulfilled. Evidence is produced to show that the principles of the lime kiln and of the gas producer work simultaneously in the furnace shaft and those of gas producer and slag formation work simultaneously in the hearth and bosh. Thermal data obtained on a blast-furnace stack at South Chicago concerning the amount of carbon solution loss are compared, and it is shown that stock travel exerts little influence on the reactions.—A. M. F.

Closed Top Furnace—A Progress Report. (*Scope*, 1952, June, 106). A brief account of high-top-pressure operation on a blast-furnace in England is given.—B. G. B.

High Top Pressures for Smoother Furnace Operation. J. R. Barnes. (*Steel*, 1952, **130**, Mar. 3, 89–92). Experiences with high top pressure on the blast-furnaces at the Republic Steel Corp. are reported. Data have been collected that show that iron tonnage is a function of wind blown, this is confirmed by a new blower fitted to No. 5 furnace which is rated at 125,000 cu. ft./min. at 35 lb./sq. in. Other records show much reduced flue dust production, reduced coke rate, and a continued higher rate of production with increased lining age compared with normal top pressure.—A. M. F.

Assessment of Blast Furnace Performance. R. P. Towndrow. (*British Iron and Steel Res. Assoc. 19th Blast Furn. Conf.*, 1951, 3–9). The complex nature of the problem is first reviewed. An examination of operating data from British plants is next made; the extreme diversity of the materials used for ironmaking is pointed out. A relationship between coke rate and total amount of materials charged per ton of iron is next discussed and the concept of 'net scrap-free burden' is introduced. Replotting of the original graphs as scrap-free carbon against scrap-free burden shows that the scatter has been reduced.—B. G. B.

The Assessment of Blast Furnace Performance. S. Klemantaski. (*British Iron and Steel Res. Assoc. 19th Blast Furn. Conf.*, 1951, 10–15). The assessment of several blast-furnaces has been carried out on the basis of an empirical equation relating coke rate to reducibility of the burden, percentage of silicon in the iron, slag volume, scrap, blast temperature, and fixed carbon in the coke. To facilitate the solution of the equation, a special calculator, of the Wheatstone Bridge type, was constructed and is described in some detail.—B. G. B.

Assessment of Blast Furnace Performance. A. Stirling. (*British Iron and Steel Res. Assoc. 19th Blast Furn. Conf.*, 1951, 15–26). Operating data obtained from blast-furnaces at Corby are examined. Calculations are given of the coke rate, based on an empirical equation, the concept of 'net scrap-free burden,' and statistical formulæ. A detailed statistical examination for predicting coke rate and iron make is made, and British basic practice is reviewed.—B. G. B.

Tap-Hole Investigations. H. M. Richardson and D. L. C. Plummer. (*British Iron and Steel Res. Assoc. 19th Blast Furn. Conf.*, 1951, 63–71). Chemical reaction between iron or slag and the tap-hole clay mixture in a working tap-hole had not taken place to any appreciable extent, but iron had penetrated a short distance into the clay. No region of solid iron between clay and molten metal was found. A 10% coal addition to normal clay (50% clay, 50% grog) gave equal performance and easier working; a 20% addition weakened the hole. The influence of the 'keeper' on the condition of the taphole is pointed out.—B. G. B.

Some Aspects of Tap-Hole Practice. W. Banks. (*British Iron and Steel Res. Assoc. 19th Blast Furn. Conf.*, 1951, 72–74). The practical operation of three types of tap-hole gun is described. These are of the electric chain rammer, electric twin screw, and electric piston types. The performance of each is discussed.—B. G. B.

Tapping-Hole Practice. D. W. E. Lloyd. (*British Iron and Steel Res. Assoc. 19th Blast Furn. Conf.*, 1951, 74–80). The location of the tap-hole and the necessity for plugging or reducing the diameter of the tuyere close to it are discussed. The design and care of the tap-hole during blowing in, and the routine opening and 'stopping up' are reviewed.—B. G. B.

The Influence of Carbon on the Interphase Tension between Iron and Slag. S. I. Popel', O. E. Esin, and Yu. P. Nikitin. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **83**, No. 2, 253–255). [In Russian]. The influence of the carbon concentration in iron on the surface tension between iron–carbon alloys and slag was investigated between 1450 and 1500° C. The results obtained showed that iron–slag interphase tension decreased with increase in carbon.—V. G.

PRODUCTION OF STEEL

The Manufacture of Low Nitrogen and Low Phosphorus Basic-Bessemer Steel. P. Coheur. (*Rev. Univ. Min.*, 1952, Series 9, **8**, Apr., 114–122). An account is given of the results of works trials using sodium carbonate and lime additions to reduce the sulphur and phosphorus contents in Bessemer steel. When the new techniques are combined with a water-vapour–steam blast, continued throughout the complete conversion cycle, a steel containing 0·019% P, 0·025% S, and 0·0021% N_2 is obtained. The results of physical tests carried out on these steels are given and they confirm that they are equal or superior to open-hearth steels.—B. G. B.

The Present Position of the Theory of Metallurgical Processes in Steelmaking in the USSR. I. Petrman. (*Hutnické Listy*, 1951, **6**, Nov., 538–541). [In Czech]. The development and recent advances of Soviet ferrous metallurgy are discussed, mainly on the basis of the 1951 Moscow conference on "The Physico-chemical Principles of Steelmaking."—P. F.

A Rapid French Metallurgical Process. A. Portevin. (*Tekn. Tidskr.*, 1952, **82**, Apr. 29, 397–401). [In Swedish]. The author discusses the principles of the Ugine-Perrin process. Details are given of the application of the process for dephosphorizing at the Tata ironworks and of its suitability for sulphur removal. Tables show steel and slag analyses before and after refining together with tensile test results. Difficulties encountered when the method was applied to a Bessemer converter and a basic open-hearth furnace are outlined.

Development of Active Mixer Practice at Appleby-Frodingham. A. Jackson. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 184–202). [This issue].

Open Hearth Rebuild Program Increases Furnace Availability. J. L. Walton and J. O. Dague. (Amer. Inst. Min. Met. Eng. Nat. O.-H. Conf., 1952: *J. Met.*, 1952, **4**, May, 465–467). At the Lackawanna plant of the Bethlehem Steel Corporation, which has 30 open-hearth furnaces, it is necessary to plan rebuild schedules two months in advance in order to maintain maximum furnace availability. The authors describe the operations in a typical furnace rebuild. An increase in production results from the rigid scheduling of this operation.—G. F.

Cupola Hot Metal Increases Steel Production, Cuts Ingot Costs. D. I. Brown. (*Iron Age*, 1952, **169**, Feb. 28, 104–107). The use of cupolas in non-integrated steelworks to provide

hot metal has been shown to increase steel production by 25%. The Central Iron and Steel Divisions of Barium Corp. are employing three 108-in. dia. cupolas with an output of 15 tons/hr. each. The average length of run is 72 hr. actual melting time.—A. M. F.

Low-Carbon Ferro-Chrome-Silicon Cuts Stainless Ingot Costs. N. B. McFarlane. (*Iron Age*, 1952, **169**, Feb. 21, 108–110). The use of low-carbon ferrochromium-silicon in place of low-carbon ferrochromium is explained; and it is said to be cheaper. This alloying material can be used in practically any kind of stainless steel production and frequently it reduces melting time.—A. M. F.

Automatic Process Controls in the Steel Industry. E. Whitehead. (*Research*, 1952, **5**, Mar., 133–139). An account is given of the types of control now being applied in the steel industry, with specific reference to automatic control of a gas booster fan, gas producers, and open-hearth furnaces. The savings in manpower and maintenance, both now and in the future, are also discussed.—C. J. B. F.

Peter Bolotov's Accelerated Melts. (*Hutnické Listy*, 1951, **6**, Dec., 599–601). [In Czech]. Principles involved in the rationalization of melting and preparing the charge, repairing open-hearth furnaces, and fuel control, as evolved by P. G. Bolotov at the Novo-Tagil works, are discussed, and a log of the entire process in the open-hearth shop is given.—P. F.

The Influence of the Distribution of C, P, and S, on the Ingot Yield of Tube-Quality Rimming Open-Hearth Steel. V. Rauner. (*Hutnické Listy*, 1951, **6**, Dec., 582–585). [In Czech]. Several experimental ingots from three melts of mild steel of carbon content 0·14–0·22% were sectioned, and sulphur prints and cupping tests were made on individual sections. The portion of the ingot suitable for the production of seamless tubes was thus determined with fair accuracy. About 65% of the ingot is usable for that purpose.—P. F.

The Removal and Addition of Nitrogen from Steel in the Basic Arc Furnace. H. Wentrup and W. Altpeter. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, Oct., No. 17, 273–296). A large number of melts (102) were investigated in three different basic electric arc furnaces. The investigations showed that the speed of refining had an overriding effect on the removal of nitrogen, which was further influenced by the furnace atmosphere, the nitrogen concentration, and the distribution of ore in the bath. A theoretical curve was calculated for the nitrogen removal and compared with experiment. The largest increase of nitrogen was by bright drawing and decarburizing, an increase of 0·001% nitrogen per hour being obtained. This was dependent upon the degree of alloying, amongst other factors. Examples of the removal of nitrogen by aluminium and ferrotitanium in the pan are given.—R. J. W.

Study of the Solidification of Steel. N. Chvorinov. (*Hutnické Listy*, 1951, **6**, Nov., 549–552; Dec., 594–598). [In Czech]. The solidification of steel ingots is considered. The definition of freezing is examined, a fundamental analysis of the mathematical problem of solidification is presented, and the implication discussed. Methods of measuring freezing rates are reviewed.—P. F.

Oxy-Natural Gas Hot-Top Heating Increases Ingot Yield. A. J. Texter and E. F. Kurzinski. (*Iron Age*, 1952, **169**, Feb. 14, 126–128). The latest answer to the old problem of hot-topping is heating with oxy-natural gas. Up to 10% increase in ingot yield is reported and the hot-top weight has been materially reduced. High-alloy and stainless steel ingots are now being poured, using this standardized method, with no bad effects on steel quality. The practice is simple and quick, and no water cooling of burners is necessary.

PRODUCTION OF FERRO-ALLOYS

Manganese for the Steel Industry. F. W. Boulger and R. C. Buehl. (*J. Met.*, 1952, **4**, May, 468). A brief description is given of trials of a two-stage process for recovering manganese from open-hearth slags, which involves producing spiegeleisen from the slags in a blast-furnace and then oxidizing it in a basic converter to obtain a high-manganese slag.—G. F.

Experimental Furnace Recovers Manganese from Slag. R. C. Buehl. (*Iron Age*, 1952, **169**, Feb. 28, 97–99). An experimental 22-ft. high blast-furnace for the recovery of manganese from open-hearth slag is described. From slag containing 2½ to 11½% Mn an iron–manganese metal containing about 60% Mn is produced which is suitable for the production of ferromanganese.—A. M. F.

FOUNDRY PRACTICE

The Fluidity of Molten Cast Iron. E. R. Evans. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Oct., 86–139). The relative effects were determined of the elements carbon, silicon, and phosphorus on the fluidity and the solidification temperature of various irons. In general, improvements in fluidity were accompanied by corresponding decreases in solidification temperature. The fluidity depends primarily upon composition and pouring temperature and may be improved by increasing the concentration of carbon, silicon, or phosphorus, or pouring temperature. Increase in carbon content is the most effective, from the point of view of composition, but an increase of 15–20° C. in pouring temperature improves fluidity as much as an increase of 0·1% C, 0·3% Si, or 0·2% P. High phosphorus content is not essential for good fluidity. The effect on fluidity of pouring temperature and of Mn, S, Ni, Cu, Cr, Mo, Ti, V, Zr, Al, Tl, B, Ce, and Mg was also determined. Tests were carried out in four foundries and the results obtained compared favourably with laboratory tests.—B. G. B.

Design of Gray-Iron Castings. T. E. Eagan. (*Mech. Eng.*, 1952, **74**, Feb., 115–117). The author recommends that the designers become more familiar with the engineering properties of grey iron and use them to the best advantage. Such factors as section thickness, machining allowance, shrinkage rules, and treatment for internal stresses are discussed.—D. H.

Where Is Cast Iron Going To? P. A. Russell. (*Proc. Inst. Brit. Foundrymen*, 1951, **44**, B110–B123). The author discusses the uses of cast iron, and relates them to manufacturing developments. The damping capacity of nodular iron and problems in its production are referred to.—E. T. L.

The Application of the High-Frequency Furnace in the Iron Foundry. C. W. Pfannenschmidt. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1940, **8**, June, No. 4, 71–78). The success of the high-frequency furnace in competing with the electric arc furnace, in spite of the necessarily higher depreciation costs, is described. The advantages of its use in a grey iron foundry are: (1) Reduction in electrode costs; (2) low power consumption; (3) simple and reliable operation, since light charging of the crucible is possible; (4) with reasonable use, less cost in the linings of the crucible. Examples of the relative savings are given.

Report on Foundry Cupolas. F. Soldat. (*Giesserei*, 1952, **39**, May 29, 265–266). Recent developments in cupola furnace design and practice, with special reference to the tuyeres, are briefly discussed.—J. G. W.

Hot-Blast Cupolas. M. Itzel. (*Gjuteriet*, 1952, **42**, Mar., 35–42). [In Swedish]. The theory of the hot-blast cupola, now being adopted in Sweden, is presented and its advantages in fuel economy and decreased sulphur are outlined. Typical hot-blast installations are described which operate by: Blast preheated by furnace gases; utilization of physical heat from exhaust gas and cupola radiant heat; blast preheated in a separate oil- or coke-fired stove; heat from exhaust gases taken up by the blast by a heat-exchanger. The last method is dealt with in detail and numerous diagrams show the layout of Moore, Cameron, Griffin, Schack, and Philipon equipment.—G. G. K.

Charging in the Iron Foundry with Special Reference to Cupola Practice. C. W. Pfannenschmidt. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1941, **9**, Sept., No. 5, 105–118). A review of the use of pig iron, cast metal scrap, and steel scrap in the foundry is made. The necessary requirements as to the condition of the charging materials are discussed. The influence on the cast iron of various melting techniques, *e.g.*, the effect of overheating, sulphur, slags, and the double melting method is described; this is followed by a brief reference to calculations of the charge.—R. J. W.

Metallurgical Possibilities When Melting Cast Iron in the Cupola. H. Kopp. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1942, **9**, July, No. 8, 165–172). The cupola need not be used except for pure melts. The possibilities of altering the melting and slagging practices, the furnace design, and screening the foundry coke in the mixture of ores are discussed with regard to their effect on the properties of the molten iron produced. Melting with additions of steel to produce low-carbon cast iron and cast iron with a normal carbon content is then discussed. The cupola, it is claimed, has thus earned a lasting place in the foundry.—R. J. W.

Some Experiences with Cupola Spark and Dust Arresters. W. Y. Buchanan. (*British Cast Iron Research Assoc. J. Res. Development*, 1952, **4**, Feb., 272–282). The development and improvement in design which have occurred in recent years are reviewed. The serious corrosion difficulties, due to sulphur compounds, which occurred in a plant using recirculation of water are described; this has now been avoided by using town water and not recirculating.—B. G. B.

Practical Experiences in Producing Nodular Cast Iron. M. M. Hallett. (*Proc. Inst. Brit. Foundrymen*, 1951, **44**, B63–B73). The author points out the need to have a low-sulphur iron before inoculation. He prefers the use of magnesium to cerium, and describes the method of adding it. The main difference between nodular and flake graphite irons is in the greater shrinkage of the former, which necessitates careful feeding.—E. T. L.

The Harmful Influence of Some Residual Elements in Magnesium-Treated Nodular Cast Irons and Their Neutralization by Cerium. H. Morrogh. (*British Cast Iron Research Assoc. J. Res. Development*, 1952, **4**, Apr., 292–314). The harmful effects of titanium, lead, antimony, bismuth, aluminium, and copper in magnesium-treated nodular cast irons are described. The influence of tin and arsenic is also considered. It is shown that small additions of cerium are capable of neutralizing the harmful elements and so permit the choice of a wider range of raw materials for the production of nodular iron by the magnesium process.—B. G. B.

Manufacture of Nodular Cast Iron. L. Barrling. (*Gjuteriet*, 1952, **42**, Apr., 55–61). [In Swedish]. The Swedish SKF are now producing nodular cast iron by the Mond Nickel Co. process, in which a magnesium alloy (15% Mg, 85% Ni) is blended with the melt at 1450° C. The author compares the cerium and magnesium processes, discusses the tensile properties of cast iron, and compares the tensile strengths of nodular and cast iron and cast steel.—G. G. K.

Nodular Iron. S. Hähnel. (*Tekn. Tidskr.*, 1952, **82**, June 10, 541–544). [In Swedish]. The Mond Nickel Co. process for producing nodular cast iron is now used in Sweden. The features of the method are described and mention is made of precautions such as precise admixture of magnesium and exact determination of the sulphur content in the charge. Preferred English and American specifications for the basic and nodular cast irons are given. Heat-treatment methods, and machining and hot-rolling qualities of the metal are discussed.—G. G. K.

Oil-Fired Rotary Furnaces. W. D. Bullows. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Aug., 21–26). The construction, operation, and fuel system of an oil-fired rotary furnace are described in detail; the fuel used is creosote pitch. Positive air and oil control are employed to achieve metallurgical balance in the furnace, to obtain known melting times, to balance mechanized production, and to increase the life of recuperator tubes. The results of three typical days' melting practice are tabulated.—B. G. B.

Practical Aspects of Duplexing. E. Kay. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Aug., 33–37). The duplexing of cupola metal in the rotary furnace, the air furnace, and the electric furnace are considered. The duplexing unit in the author's own works is the rotary furnace, and increased production is one of the advantages claimed. Molten metal from the cupola is transferred to a 3½-ton ladle (desulphurization is carried out at this stage by soda ash) and thence to a rotary furnace, already containing the steel charge, where it is superheated in approximately 50 min. A tensile strength of 24–28 tons/sq. in. and an elongation of 14–18% are obtained.—B. G. B.

Pulverized Fuel Furnaces for Melting Malleable Cast Iron. H. W. Perrott. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Aug., 1–15). The development of the modern air furnace and the application of pulverized fuel firing are reviewed. The methods of grinding fuel and distributing it to the furnace are considered in detail. The performance of various pulverized fuel-fired installations in England are reviewed; these include unit pulverizer and central pulverizer plants for air furnaces melting black-heart malleable iron, air furnaces for duplexing, the Brackelsburg furnace for melting and duplexing, and the Sesci furnace.

Pulverized Fuel Furnaces for Annealing Malleable Cast Iron. H. W. Perrott. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Aug., 39–53). The ring main method of distributing fuel is described in detail; only one feeder and fan are used with individual valves at each oven. Air control is very important. Various types of annealing furnace, fired by pulverized fuel, are described and operating data for each are given. In continuous bogie oven practice, an overall cost of less than £8/ton of castings annealed is claimed.—B. G. B.

The Gaseous Annealing Process. K. Roesch. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Aug., 55–57). An annealing furnace heated by radiant tubes is described. Comparative heat-treatment curves for three types of gaseous annealing furnace are given together with operating statistics of gaseous and pit-type annealing furnaces.—B. G. B.

Annealing Blackheart Malleable Cast Iron in a Controlled Atmosphere Furnace. E. Hunter. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Aug., 59–66). A detailed description of radiant tube bell-type furnaces, for annealing black-heart malleable cast iron, which have recently been installed in this country is given; the furnace is fired with producer gas. The temperature of the radiant tubes and of the charge itself is carefully controlled. The complete cycle, including preheating, soaking, fast cool, equalizing, and slow cool takes 87 hr. The chief advantages claimed are the elimination of annealing boxes, a saving in fuel, and cleanliness.—B. G. B.

Metal Composition and Annealing of Blackheart Malleable Cast Iron. P. H. Shotton. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Oct., 68–73). The effect of composition and annealing on the quality of the highest grade of black-heart malleable cast iron to British Standard 310: 1947 as melted in the air furnace or rotary furnace is discussed. The carbon/silicon and manganese/sulphur ratios and the phosphorus content are considered. The mechanism of the process is also discussed.—B. G. B.

Production of High Quality Whiteheart Malleable Cast Iron. K. Roesch. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Oct., 74–77). Two methods have been investigated: (1) Secondary annealing to modify pearlite; and (2) melting a low-sulphur and low-silicon malleable cast iron high in manganese. A material of extraordinary toughness is obtained by suitable annealing.—B. G. B.

Modern Malleablizing Furnace Technique. K. Borchart. (*Giesserei*, 1952, **39**, Apr. 17, 171–179). The article is principally concerned with the gas malleablizing process, which is now also finding favour in Germany. The novel furnace designs needed for this process are described, and cost comparisons are given for white-heart malleable iron.—J. G. W.

Malleablizing Pots. A. Sprengepiel. (*Giesserei*, 1952, **39**, May 1, 216–217). The design and life of pots of grey iron, malleable iron, Armco iron, and cast steel, in which small castings are packed for malleablizing, are discussed.—R. A. R.

Annealing in a Tunnel Furnace. A. Sprengepiel. (*Giesserei*, 1952, **39**, May 15, 240–241). A description is given of a gas-fired tunnel furnace for the treatment of malleable iron castings in boxes.—R. A. R.

Determination of Pipe Formation in Malleable Castings. A. Bordes. (*Giesserei*, 1952, **39**, May 1, 201–203). A new method for determining the propensity for piping is described, in which a rounded cone is bottom poured. Data on the influence of melting procedure on pipe formation are quoted.

Process Control of Cast Iron for Vitreous Enamelling. J. Bernstein. (Inst. Vitreous Enamellers: *Found. Trade J.*, 1952, **92**, June 5, 603–606). Vitreous enamelling gives an attractive surface and protection against corrosion. Success in enamelling needs a sound casting, with gradual changes of thickness and no sharp corners. The author points out the need for laboratory control of the quality of the moulding sand.—E. T. L.

The Sand Triangle. H. Jungbluth. (*Giesserei*, 1952, **39**, May 15, 225–232). The relation between water content, gas permeability, and compression strength of moulding sand varies with the compacting process. This relationship is investigated on the basis of a ternary constitution diagram, the three variables being solids, pores, and water.—J. G. W.

A Contribution on the Metallic Mould Blowing Reaction. V. Kondic, G. Martin, and K. Bromage. (*Metallurgia*, 1952, **45**, Mar., 127–130). The conditions under which a chemical reaction at the metal–mould interface may give rise to ' blowing ' at the surface of a chill casting were studied. The results show that the reaction, which is essentially one of oxidation of the carbon in the mould material, can be treated quantitatively with a good approximation by using the thermodynamic data of the substances involved. By providing at

the interface, metals having higher affinity for oxygen than that of carbon, the reaction can be reduced and the 'blowing' completely eliminated.—B. G. B.

Oxide Inclusions when Casting Steel. H. Wentrup and F. W. Linder. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, Dec., No. 19, 313–338). Theoretical considerations of the deoxidizing effect of carbon, silicon, manganese, and aluminium are given. The change in the steel and slag analyses during casting is noted and followed by a description of the inclusions formed during casting. The compositions of the inclusions in the various parts of the castings, *e.g.*, in the runners and slag, are given and are plotted in numerous SiO_2–MnO–Al_2O_3 ternary diagrams. Finally, the effect of the material of the mould on the inclusions is discussed.—R. J. W.

Repair of Castings by Means of Synthetic Materials. K. Holeš. (*Hutnické Listy*, 1951, **6**, May, 229–231). [In Czech]. Research on the elimination of microporosity in castings is described. Bakelite and other synthetic lacquers may be used. Castings were placed in a vessel which was evacuated, the lacquer was then admitted, finally a pressure of 20 atm. was applied to the lacquer in which the castings were submerged. Microcracks were thus filled up. After removal of the castings from the container, the former were wiped and baked. Experience thus gained showed that the bakelite lacquer was superior to all others tried; no bubbles appeared on baking. Many rejected castings have been saved by this method.—P. F.

Practical Consequences of Space, Time and Temperature Relations during Casting of Metals. J. S. Abcouwer. (*Amer. Found. Soc. Preprint*, 1952, No. 19). A mathematical treatment gives the temperature distribution in a casting. As a consequence, pouring time and the sizes of ingates, risers, and heads can be deduced for any practical case in which the factor $a_1 t/X^2$ is the same as in a successful geometrically similar case (where a_1 is the temperature diffusivity of the metal, t is time, and X is the volume/surface ratio).—E. T. L.

Casting Defects and Their Causes. J. Drachmann and A. Öhman. (*Gjuteriet*, 1952, **42**, Feb., 19–24). [In Swedish]. The Swedish committee examining defects in castings has issued a further list of faults and causes. Sections deal with castings distorted by internal and external stresses, incomplete filling, and cold pouring. Remedial design and moulding techniques are given. Faulty trimming methods are also dealt with.—G. G. K.

Causes of Faults in Machine Tool Castings. E. Brands. (*Giesserei*, 1952, **39**, May 29, 267–268). Common faults such as blowholes, sand inclusions, and cracks, are discussed with reference to the casting of machine tool components, and remedies are described.—J. G. W.

The Whys and Wherefores of Statistical Quality Control. W. R. Weaver. (*Amer. Found. Soc. Preprint*, 1952, No. 16).

Incorporation of Dust Control in Foundry Planning. J. Hunter. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Dec., 152–161).

Fans: Their Characteristics and Factors Governing Their Selection. R. H. Young. (*British Cast Iron Research Assoc. J. Res. Development*, 1952, **4**, Feb., 210–221). Centrifugal, axial flow, and propeller types of fan and their performance are discussed.—B. G. B.

Dust in Foundries. W. B. Lawrie. (*British Cast Iron Research Assoc. J. Res. Development*, 1952, **4**, Feb., 222–237). To determine the silicosis risk the measurement of the dust must show the atmospheric concentration of particles less than 5 microns in dia. A number of methods of measuring the concentration of dust in the atmosphere are discussed.—B. G. B.

Fume and Dust Extraction at the Knockout. L. W. Bolton. (*British Cast Iron Research Assoc. J. Res. Development*, 1952, **4**, Feb., 238–248). Side suction ventilating equipment has been successfully adopted in a fully mechanized foundry producing castings up to 5 cwt. in weight. An average air current of 2500 ft./min. at the mouth of a suction hood is completely effective in removing the whole of the fume and dust when shaking out castings at temperatures up to 700° C. 3 ft. 6 in. from the hood mouth.—B. G. B.

Natural Ventilation. L. G. Davies. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Dec., 182–192). Natural ventilation systems in foundries depend largely upon thermal currents inside and wind power outside the building; the design should be based on the former, since this is likely to be more stable. Numerous small controlled openings in the roof are preferable to fewer and larger openings. The question of radiant heat from inside and outside the building is considered and ventilator design is examined.—B. G. B.

Ventilation Methods in Swedish Foundries. K. Nilsson. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Dec., 193–201). The occurrence of CO in foundry air is discussed. The author recommends total enclosure of cooling operations, sand-blasting, furnaces, knock-out stations, oxy-acetylene cutting, grinding, etc. In local enclosures the exhaust system should be situated as close as possible to the point of generation of dust and fumes.—B. G. B.

Industrial Lighting. F. Jamieson. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Dec., 173–181). The necessity for a maintenance schedule for lighting systems is stressed and formulæ are given for determining the monthly depreciation rate of illumination and the interval between cleaning.—B. G. B.

On Economic Illuminating Engineering in Foundries. H. Timmerbeil. (*Giesserei*, 1952, **39**, June 12, 281–287). The fundamentals of illuminating engineering are explained. The author recommends low-voltage fluorescent lighting.—J. G. W.

Improvement of Working Conditions in Foundries: Survey of Problems Involved. W. B. Lawrie. (*British Cast Iron Research Assoc. J. Res. Development*, 1951, **4**, Dec., 142–151).

Safety Regulations—Basis of Accident Prevention. H. Jönsson. (*Gjuteriet*, 1952, **42**, Apr., 63–65). [In Swedish]. Extracts quoted from a safety handbook, issued by a Swedish shipyard to all employees, deal with rules for accident prevention in the foundry.—G. G. K.

Apprentice Training—It Is Needed. M. C. Sandes. (*Amer. Found. Soc. Preprint*, 1952, No. 17). In 1950 there were about 1500 American apprentices training in moulding and core-making, which means one apprentice to 35 craftsmen already employed. The author points out that this rate of training is insufficient and suggests remedies.—E. T. L.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Lindberg Mechanized Batch Type Furnace for Controlled Atmosphere Heat Treating. N. K. Koebel. (*Metal Treating*, 1952, **3**, Mar.–Apr., 2–4). The furnace, its main features and capabilities, are described in detail. Trays up to 24 × 36 × 15 in. high can be accommodated for annealing, hardening (in built-in quench tank), carbon correction, case-hardening, or carbonitriding.—P. M. C.

How to Harden Small Steel Parts. K. Rose. (*Mat. Methods*, 1952, **35**, Apr., 112–115). Some general observations and suggestions on ways to avoid precooling, prevention of decarburization, and methods of conveying work through furnaces are made. Some typical installations for heat-treating small parts are described.—P. M. C.

Heat Treating Machines. H. C. Knerr. (*Metal Treating*, 1952, **3**, Mar.–Apr., 6–8, 15). Several ingenious mechanical devices are described which permit a great variety of heat-treating operations, using flame heat.—P. M. C.

'Allcase' High Production Batch Type Furnace. R. J. Light. (*Metal Treating*, 1952, **3**, Mar.–Apr., 4, 5). The main design features and operation of two sizes of this furnace, made by the Surface Combustion Corp., are described. Built-in quenching tanks are used.—P. M. C.

Recommendation for Design and Operation of Molybdenum-Wound Hydrogen Atmosphere Furnaces. W. P. Keith. (*Bull. Amer. Ceram. Soc.*, 1952, **31**, Mar., 76–78: *Indust. Heating*, 1952, **19**, Apr., 630). The furnaces described have found wide use in the manufacture of carbide tools, and radio tubes, in wire drawing, metal sintering, brazing, heat-treating, and research.—E. C. S.

Close-Tolerance Steel Parts Austempered without Distortion. J. Kolb. (*Iron Age*, 1952, **169**, Apr. 3, 142–144). High tolerances are being obtained in the heat-treatment of rocket motor bodies. A modified austempering process using automatic, continuous salt baths and a conveyor system is employed. The parts are tempered at a temperature higher than that of quenching, resulting in a fully bainitic structure with a hardness of 34–39 Rockwell C.—A. M. F.

Flame Hardening. N. W. Johnston. (Australian Inst. Metals: *Australasian Eng.*, 1952, Jan. 7, 73–78). In a general account of this subject the author deals with the advantages and methods of flame-hardening (spot, progressive, spin, and progressive spin methods). Stress relieving, quenching, and the equipment used are also reviewed.—P. M. C.

Peddinghaus Automatic Flame Hardening Machines. (*Machinery*, 1952, **80**, Mar. 6, 430–432). The machines, developed by Paul Fred. Peddinghaus, Gevelsberg, Germany, employing oxygen and town gas, and the Milliscope pyrometer system which automatically controls the temperature of the work are described.—E. C. S.

Temperature Controlled Flame Hardening. (*Metallurgia*, 1952, **45**, Mar., 135–137). A device is described which enables temperature rises far in excess of the heating speed to be measured. A photocell compares radiation from a control filament and the work surface; comparison is made for a particular wavelength range by using optical filters. The application of this device to flame-hardening control and other purposes is described.—B. G. B.

The Annealing Problem in the High-Class Welding of Boilers, Vessels and Plant. H. Busch. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1942, **9**, Oct., No. 9, 179–192). The advantages of high-quality welding are discussed. Large annealing furnaces are described and the difference between normalizing and a stress-relieving anneal is clarified. The conditions required for a 'stress-free anneal' are given. The slight ageing effect in various plates is discussed, especially the useful case for low-temperature vessels (− 50° C.). The notched-bar toughness is given for the material investigated and the welded specimens at both room temperature and − 50° C. Finally, the annealing of alloy steels for boiler construction is discussed.—R. J. W.

Bright Annealing of Steel Strip in Grünewald Furnaces with Protective Gas, without Water Cooling. H. Pannek. (*Stahl u. Eisen*, 1952, **72**, Apr. 10, 423–425). Although attempts to remove all oxygen from a burnt gas protective atmosphere have failed, it has been found possible to produce a bright annealed strip by changing the normal 10–15 mm. wide water-cooled gasket on the annealing cover to one 90 mm. wide consisting of concentric rings of asbestos, rubber, and asbestos. The advantages to be gained from absence of water cooling are listed.—J. P.

Hardening High-Speed Steels. (*Machinery Lloyd, European Edition*, 1952, **24**, May, 79). The unit described consists of two furnaces, one a preheating chamber operating at temperatures up to 940° C. and the other, the hardening chamber, for temperatures up to 1350° C. Details of their construction and temperature controls fitted to each are given. Each chamber can be supplied with a protective atmosphere if required.

Some Ideas on the Quenching Operation. J. E. Hyler. (*Steel Processing*, 1952, **38**, Mar., 135–138, 153). Handling and cooling problems are briefly reviewed. A special layout for transferring annealing pots from furnace to quenching machine by means of a light overhead bridge crane is described.

FORGING, STAMPING, DRAWING, AND PRESSING

Fundamentals of Forging and Forming. H. A. Clark. (*Indust. Gas*, 1951, **15**, Dec., 84–90). The author discusses flow lines, temperatures, presses, hammers, upsetting, and reheating furnaces.—D. H.

The Mechanical Technology of Shaping Processes. E. Siebel. (*Metallwirtschaft*, 1943, **22**, Sept. 20, 423–428). An historical survey of the development of the mechanical technology of shaping processes leads to a discussion of the theories of the strength of materials and their experimental support. The effect of varying the physical conditions, *e.g.*, the rate of deformation, on the flow curves of various materials, and the plastic deformations, are discussed. The deformation processes that occur, the effective forces acting and their distribution during forging, rolling, and wire drawing are considered in detail. Tube and rod drawing and other compression processes such as extrusion are treated similarly. Flow experiments using soft lead are described.—R. J. W.

The Hot-Forging of Metals. H. K. Breton. (*Machinery*, 1952, **80**, Mar. 6, 410–414). The author discusses drop forging, hot-pressing, and stamping.—E. C. S.

The Hot Forging of Metals. H. K. Barton. (*Machinery*, 1952, **80**, Apr. 17, 679–683). Hot-forging tools are considered in three groups in which: (1) Deformation is not carried sufficiently far to produce a defined flash; (2) a flash is formed between the two members; and (3) the formation of a flash is deliberately prevented.—E. C. S.

The Hot Working of Metals. H. K. Barton. (*Machinery*, 1952, **80**, May 15, 848–852). The construction and uses of horizontal forging machines are considered.—E. C. S.

Wilkins & Mitchell Forgemaster Forging Presses. (*Machinery*, 1952, **80**, Apr. 17, 694–696). Some features of the new range of 'Forgemaster' presses developed by Wilkins and Mitchell, Ltd., Darlaston, are described. The capacities range from 600 to 3000 tons and the operating speeds from 110 to 80 strokes/min.—E. C. S.

Precision Control Speeds Shell Production. W. G. Patton. (*Iron Age*, 1952, **169**, Apr. 3, 127–131). At the Chevrolet St. Louis shell plant, artillery shells are being produced in 55 operations which include cutting the billets, heating, forging, heat-treatment, machining, and transport. During this sequence 41 different inspections take place. A successful training programme has been an important factor in the plant operation.—A. M. F.

Unusual Forging Machine Upsets 40 Times Bar Diameter. F. Darmara. (*Iron Age*, 1952, **169**, Mar. 13, 100–102). An electrical resistance upset forging machine capable of upsetting as much as 40 to 50 diameters is described. Jet-engine blades are formed from $\frac{3}{8}$-in. bar 18 in. long of which $11\frac{1}{2}$ in. is upset. The machine combines resistance heating with a hydraulic pushing ram and a moving anvil. Close control is achieved without the use of dies and production rates as high as 600 pieces/hr. depending on stock size can be attained.

Modern Extrusion Plant. (*Metallurgia*, 1952, **45**, Apr., 173–177). A new extrusion plant incorporating a 2000/200-ton horizontal extrusion press with the necessary billet-handling and heating equipment is described. The press is of the three-column type and has an automatic speed control. Special features mentioned include the automatic control of temperature, the application of pneumatic cylinders to the handling equipment, and the new coiling machines.—B. G. B.

The Die-Block Plant of Walter Somers, Limited, Halesowen. (*Engineering*, 1952, **173**, May 16, 617: *Brit. Steelmaker*, 1952, **18**, June, 292–296). **Quick-Acting Forge for Die-Block Manufacture.** (*Iron and Coal Trades Rev.*, 1952, **164**, May 23, 1152). Brief details are given of the new shops of Walter Somers, Ltd., near Birmingham, for the production of die blocks. The plant is laid out so that the material progresses in a uniform sequence of operations and without retracing its path from the store to final inspection. The estimated output is 400 tons/month.—M. D. J. B.

New Forge and Heat-Treatment Plant for Die-Block Manufacture. L. H. Williams. (*Metal Treatment and Drop Forg.*, 1952, **19**, Apr., 155–165). The author describes in detail the new plant and equipment installed at Walter Somers, Ltd., Halesowen, Birmingham.—P. M. C.

Vauxhall Door Line Integrates Presses and Press Welders. W. A. Hawkins. (*Machinist*, 1952, **96**, May 17, 737–741). Continuous flow of work from the first press operations on the panels to the last assembly operation on the door unit is achieved by layout of the car door line and the equipment provided to facilitate work handling at Vauxhall Motors, Ltd.

Fabricated Deep Drawing Press. (*Welding Metal Fab.*, 1952, **20**, May, 158–161). A 1200-ton triple-action hydraulic deep-drawing press for metal work is described and illustrated.

25 Years in the Sheet-Metal-Working Industry. J. W. Langton. (*Sheet Metal Ind.*, 1952, **29**, Apr., 293–300). The author briefly surveys developments in pressing machines, guillotines, and bending and rolling machinery.—P. M. C.

The Neutral Line and Its Application to Bend Allowances. A. Dickason. (*Sheet Metal Ind.*, 1952, **29**, Apr., 327–331, 333). The author discusses the neutral line with reference to sheet metal bending operations and gives a method for its calculation.—P. M. C.

Press Load Calculations: Electronics Replaces Theory. (*Steel*, 1952, **130**, Mar. 10, 112–113). An electronic device has been developed which measures the loads arising in press operations; it indicates and records accurately maximum or instantaneous tonnage during each stamping cycle and can stop the press when any predetermined overloading occurs. Thus a coining or other operation can be set to the machine capacity. Signals are derived from strain gauges mounted on each press guide rod.—A. M. F.

The Manufacture of Ribbed Tubes. E. Hörmann. (*Z.V.d.I.*, 1952, **94**, Apr. 21, 343–345). The internal upsetting of tubes with the aid of local induction heating is described.—J. G. W.

New Machine Forms Jet Rings. (*Iron Age*, 1952, **169**, Mar. 27, 106–107). A machine is described which forms rings by taking partially preformed strip, sheet, or plate, putting it in tension between two jaws, and then wrapping it around

a die. Little or no finish-machining is required and varied shapes may be formed.—A. M. F.

A South African Wire Works. (*Wire Ind.*, 1952, **19**, May, 460–461). A brief history and a description of the wire works of the Union Steel Corporation of South Africa are given. These produce both steel and copper wire.—J. G. W.

Measurement of Die Pressure in Wire Drawing by Photoelastic Methods. P. M. Cook and J. G. Wistreich. (*Brit. J. Appl. Phys.*, 1952, **3**, May, 159–165). Wire drawing has been simulated by drawing lead–tin alloy strips through a wedge-shaped die made of a stress-sensitive plastic, and the pressure normal to the die surface has been measured by the photoelastic method. The accuracy of the graphical method of stress computation was enhanced by the use of alternative methods. The pattern of isoclinics was found to be unusual and necessitating modification of the normal computational procedure. The results are in good agreement with the theory of Hill, extended by Green.—E. T. L.

The Calculation of the Drawing Forces and Conditions of Stress in Wire Drawing. T. Pöschl. (*Metallwirtschaft*, 1943, **22**, Sept. 20, 428–434). Utilizing the conception of an idealized stress–strain curve, a method was developed to calculate the drawing forces and conditions of stress during wire drawing. The elastic forces are first considered as the wire goes through the die. Further calculations, during and after the transition to the region of plastic flow, yield expressions from which the drawing forces can be obtained. Calculations of the various stress components within the wire are given and illustrated by numerical examples. The effects of drawing angle, and reduction in cross-section, enter into these calculations. The suitability of various materials for drawing is considered.

New Instruments for the Inspection of Die Profiles. A. Pomp. (*Z.V.d.I.*, 1952, **94**, Apr. 21, 305–306). The 'Alfa- and Zet-meters' are briefly described and illustrations of their use are given. These show that many faults encountered in die profiles can be eliminated if these instruments are used to control the shaping operations.—J. G. W.

ROLLING-MILL PRACTICE

Electrical Plant for the Metal Industries. (*Metallurgia*, 1952, **45**, Mar., 137–138). A review is given of electrical installations made by the Metropolitan-Vickers Electrical Co., Ltd., during 1951. The bulk of the equipment was connected with rolling-mill main drives (total 27,000 h.p.), some of the machines having electronic control devices. Several auxiliary drives were also put into commission.—B. G. B.

Model Mill Rolls Model Rail. D. Cox and W. P. Wallace. (*Iron Age*, 1952, **169**, Apr. 3, 140–141). A model rolling mill for demonstration purposes is described. Wire 0·162 in. in dia. is rolled continuously in four passes into a rail section. One pass includes a horizontal roll.—A. M. F.

A New Hot Mill for Strips up to 24 in. Wide. M. Langen. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 203–214). [This issue].

Electric Drives for Continuous Hot Mills. G. R. Wilson. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 215–225). [This issue].

Russian Experience of Phosphorus in Steel Sheet. J. Teindl. (*Hutnické Listy*, 1951, **6**, Nov., 546–549). [In Czech]. The sticking of sheets to the rollers in hot rolling is discussed, and the effect of additions of silicon and phosphorus to prevent sticking and to improve the surface of black sheet is examined. The influence of increasing the phosphorus up to 0·12% in tinned sheets is studied by the number of rejects and the Erichsen test. The melting of high-phosphorus steels is dealt with, and experimental results of mechanical tests on sheets of different steels are presented. Increasing the phosphorus is preferable to increasing the silicon. Best results were obtained with steels containing 0·09–0·12% C, 0·14–0·18% Si, 0·30–0·40% Mn, 0·09–0·12% P, and less than 0·05% S.

Steel Mill Shipped to Norway. (*Iron Steel Eng.*, 1952, **29**, May, 124–126). This article describes the dismantling of a 32 in. × 60 in., 3-high sheet mill at New Castle, Pa., for shipment and re-erection in the plant of A/S Norsk-Blikvalseverk in Norway.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Chain Slings. G. D. Keeble. (*Mech. Handling*, 1952, **39**, May, 204–207). Details are given of a system of control and maintenance for slings. Typical causes of failure are discussed.

Mechanical Handling Plant for Coal, Coke and Ash. B. C. Morton. (*Mech. Handling*, 1952, **39**, May, 202–203). The author describes methods used for the mechanical handling of coal, coke, and ash.—D. H.

Engineered Protective Grounding for Steel Plants. K. S. Kuka. (*Iron Steel Eng.*, 1952, **29**, May, 88–95). After briefly discussing the effects of different shock currents on the human body the author makes a detailed study of the problem of protective grounding in steelworks. The limitations of grounding systems are examined and the most suitable methods of providing security in steelworks are described.

Maintenance Testing of Electrical Apparatus. L. W. Smith. (*Eng. J.*, 1952, **35**, May, 483–486, 490). The use of A.C. dielectric loss and power-factor insulation tests for preventative maintenance of electrical apparatus is discussed. These tests are used for the routine testing of bushings, cables, capacitors, circuit breakers, generators, insulators, voltage regulators, and transformers.—B. G. B.

Scrap Baling Press. (*Iron Steel Eng.*, 1952, **29**, May, 182). A brief note is given on the high-capacity Lindemann scrap-baling press. The press has triple compression with feed hopper for open-hearth steel plants and produces bales weighing up to 4 tons at 20 bales/hr.—M. D. J. B.

Scrap Steel Baler Saves Thousands. (*Mech. Handling*, 1952, **39**, May, 200–201). The paper briefly describes a new hydraulic baling press installed by Vauxhall Motors, Ltd. It was designed and built by the Loewy Engineering Co., Ltd. The working pressure is 2 tons/sq. in. and the normal load is 7 cwt.—D. H.

Fabricated Ingot Cars Stand Up under Severe Operating Conditions. R. G. Fournie. (*Iron Age*, 1952, **169**, Feb. 28, 112–114). Details of the design and fabrication of ingot cars for the Laclede Steel Co. are given. Normal operation includes repeated heating and cooling up to 1200° F. The live load is 42 tons and severe impacts at high temperatures occur.

New Type Cutter Developed for Rods, Wire and Rope. E. Jasper. (*Wire and Wire Products*, 1952, **27**, Mar., 264–265, 309). Particulars are given of a hydraulically operated cutter working at a pressure of 10,000 lb./sq. in.—J. G. W.

Bending Roll Design Analysis. E. A. Randich. (*Product Eng.*, 1952, **23**, Jan., 133–135). The author gives an accurate method for the calculation of the data needed for the detail design of bending rolls. The forces acting on the rolls are analysed and equations derived for the diameters of top and bottom rolls to curve plates of different widths and thicknesses.—A. M. F.

Dynamometers. Kh. N. Dement'ev. (*Zavodskaya Laboratoriya*, 1950, No. 2, 207–211). [In Russian]. After a consideration of the special characteristics required of dynamometers and a review of the main types, new Russian designs are described. A brief note on the checking and use of dynamometers is given.—S. K.

LUBRICANTS AND LUBRICATION

Rolling Mill Lubrication. (*Metal Ind.*, 1952, **80**, Apr. 25, 327; *Iron Coal Trades Rev.*, 1952, **164**, May 9, 1041–1042). Brief details are given of an improved design of automatic greasing lubrication battery installed by C. C. Wakefield and Co. on the 42-in. Davy reversing slabbing mill at the Appleby-Frodingham Steel Co., at Scunthorpe. The unit is responsible for the lubrication of the main mill bearings and breast rolls.—P. M. C.

Modernizing Lubrication of Old Mills. W. Holland. (*Iron Steel Eng.*, 1952, **29**, May, 76–78). The benefits which may be derived by modernizing lubrication systems on old mills are discussed and methods of carrying out the improvements described. Conversions from oil to grease are discussed as well as centralized and automatic lubrication systems.

Squirt Outdoes Flood in Cooling Cutting Tools. R. S. J. Pigott and A. T. Colwell. (*S.A.E. J.*, 1952, **60**, Apr., 45–48). The 'Hi-Jet' system of lubrication and cooling in metal cutting operations with a very fine high-speed jet of coolant projected upwards between tool and workpiece is discussed.

Lubrication and Cooling of Cutting Tools. (*Engineer*, 1952, **193**, Apr. 18, 535; *Machinery*, 1952, **80**, May 8, 806–809). Developments in cooling and lubrication of cutting tools are reported, one new method being the high-speed jet described by R. S. J. Pigott and A. T. Colwell (*see* preceding abstract). R. A. R.

Phosphate Coatings as Lubricants in the Severe Cold Forming of Metals. I—General Description. S. Spring. (*Iron Steel Eng.*, 1952, **29**, May, 64–67). The author describes the phosphatizing of metals for severe forming operations involving the formation

of a substantial deposit of a crystalline metal phosphate strongly attached to the surface. The phosphate coating functions as a lubricant in keeping the surface of the steel part being worked from coming to within molecular distances of the tool used to work it. The method combines excellent lubrication with ease of application. The solutions are dilute and not particularly corrosive.—M. D. J. B.

Phosphate Coatings as Lubricants in the Severe Cold Forming of Metals. II—Application. L. K. Schuster. (*Iron Steel Eng.*, 1952, **29**, May, 67–71). The advantages of these coatings are discussed and their application to stampings, wire drawing, tube drawing, deep drawing, and cold extrusion of steel is examined.—M. D. J. B.

WELDING AND FLAME-CUTTING

Preheating for Welding. A. B. Tesmen. (*Welding J.*, 1952, **31**, Apr., 306–313). Metallurgical principles involved in preheating for welding are discussed and a chart is given showing recommended preheat temperatures for plain carbon and alloy steels.—U. E.

Heat Treating Properties of Low Hydrogen Electrode Weld Metals. D. C. Smith and W. G. Rinehart. (*Welding J.*, 1952, **31**, Apr., 296–305). An investigation on the effect of heat-treatment on the mechanical properties of weld metal deposited by high-tensile steel electrodes is reported.—U. E.

Effect of the Type of Electrode on the Shape of the Weld Bead. A. A. Erokhin. (*Avtog. Delo*, 1949, No. 11, 14–21). [In Russian]. In the experiments described, beads were deposited on 12 × 60 × 250 mm. plates of low-carbon and chromium–nickel steel with various electrodes. The properties of beads produced by each electrode under a wide variety of conditions were studied. The following conclusions are drawn: (1) The type of electrode has an important influence on bead shape; and (2) the shape parameters independent of welding conditions are the depth/width ratio of the fused zone and that of the height to width of the raised portion.—S. K.

Welding Medium-Carbon Steels with TsM-7 Electrodes. A. A. Shapiro and K. M. Lun'kov. (*Avtog. Delo*, 1949, No. 11, 23–25). [In Russian]. In the investigation described, the properties of welds produced in medium-carbon and other steels using electrodes with a hematite–feldspar–ferromanganese–starch–waterglass coating were investigated. Specimens were cut from welded pairs of 280 × 400 × 8 mm. plates. Results of strength and hardness tests and the composition of the deposited metal and the microstructures of the various zones are given. The electrodes failed to give sound joints when welding a medium-carbon and a chromium steel.

Multiple-Arc Welding. K. V. Zvegintseva. (*Avtog. Delo*, 1949, No. 7, 1–4). [In Russian]. A new arc-welding process is proposed for dealing with thin metals, particularly stainless steels 1·2–1·5 mm. thick. The method, which permits the independent regulation of the heat input to the electrodes and the work, requires two carbon and one metallic electrodes. The two carbon electrodes, one of them earthed, are fed from a single welding transformer through a choke and resistance, and are fixed in a holder at an angle of about 30° to each other. The metallic electrode, fed from a special welding transformer through a rheostat, is held in an ordinary holder. Five arcs are formed. The heat transfer from these to the work is discussed, and optimum conditions for the welding of stainless steel of various thicknesses are tabulated. Such conditions were used for YalT steel and gave welds with a dendritic structure shown by X-ray examination to be free from pores, inclusions, or cracks. No significant increase in carbon, nor oxidation loss of chromium, nickel, or titanium as a result of welding were detected, and there was no tendency to intercrystalline corrosion. The results are given of tensile and elongation tests on the base metal and on welded specimens at 15, 500, 700, and 850° C., which showed the thermal stability of the welds. Ductility and bend tests at room temperature confirmed this. Macro- and microstructures of welds obtained by the new method are illustrated. In general, the quality of the joints obtained was as high as of those from oxy-acetylene or atomic hydrogen welding, whilst the welding rate was higher. The greater degree of control and arc stability of the new method greatly reduces the number of failures when welding thin metals.—S. K.

Experiments and Practical Conclusions on Residual Stresses. R. Weck. (*Inst. Soldadura, Pub.*, 21, 1951, 5–38). [In Spanish]. The problems of measuring residual stresses from the point of view of the most suitable measuring equipment and of the possible errors are studied. The author also considers theoretical suppositions which cannot always be confirmed but which often limit the value of these measurements. He then studies the reaction stresses produced by the transverse contraction in the weld and the influence of the different runs on the type of butt joint. The relationship between residual stresses and brittle fracture, with or without notch, at low temperatures, and also the possibility of cracking by corrosion in materials subject to residual stresses are examined.—R. S.

Welding of Stainless and Heat Resisting Steels to Ordinary Steels. B. Hermelin. (*Acciaio Inossid.*, 1951, **18**, Nov.–Dec., 9–14; 1952, **19**, Jan.–Feb., 6–12). [In Italian]. The author studies welding stainless steel to ordinary steel. The structure of mild and stainless steels is examined in detail and reference is made to Schaeffler's diagram. The structure and characteristics of the weld metal and the influence of the weld metal on the base metal and *vice versa* are examined. The dangers of corrosion, if incorrect welding technique is adopted, are stressed.—M. D. J. B.

Weld Metal in the Welding of Steel. A. Matting. (*Ciencia y Tec. de la Soldadura*, 1951, **1**, Nov.–Dec. [In Spanish]. The requisite properties of the weld metal according to the various welding processes are discussed. The development of welding rods in gas welding and the influence of the electrode in electric welding are reviewed. Causes of defects in welding are examined. Cracking, the behaviour of weld metal in fusion, and some types of coating are considered.—R. S.

Radiographic Inspection of Welds. A. Ruiz Rubio. (*Ciencia Tec. Soldadura*, 1951, **1**, Nov.–Dec.). [In Spanish]. Some advantages and uses of X-rays in inspection of welds are described. The Spanish Institute of Welding uses a Philips' Metalix apparatus of 150 kV. and 20 milliamp. which operates on steel up to 5 cm. thick and light metals up to 30 cm. thick.

Radiography of Pipe Welds with Isotopes. J. G. M. Turnbull. (*Welding Metal Fab.*, 1952, **20**, Feb. 70–73). A welded steam pipe was investigated using radiography with isotopes, and the use of isotopes in this field is discussed in detail.—U. E.

Safe Practices for Welding and Cutting Containers that Have Held Combustibles. (American Welding Society, 1952).

How to Get More Out of Resistance Welding Control. W. E. Large. (*Steel*, 1952, **130**, Jan. 28, 68–69, 81). The possibilities of using the ignitron valve as a high-current switch with precise control are discussed. It is possible by selection of the proper system to double the capacity of a welding control. Curves are given showing the rating of ignitron valves for 200 and 400-V. applications. and also electronic contactor ratings.—A. M. F.

Welding Repair of a Plate Roll Spindle. (*Schweissen u. Schneiden*, 1952, **4**, Mar., 87–88). A broken spindle 13 in. in dia. of a plate mill was repaired by electric welding using covered electrodes. The technique is described.—U. E.

Outstanding Welding Repairs on Hot Blooming Mill Shears. E. E. N. Bernhard and P. A. Dixon. (*Welder*, 1952, **21**, Jan.–Mar., 2–7). A new system, called the 'barrier system,' of welding has been developed in the repair of a casting. Cracking, caused by a major weld in the bottom blade-holder or apron of hot-bloom shears was arrested in the following manner: Three barriers, each 2 in. wide were welded 1½ in. apart, the first one joining up with the main weld. The cracks in the zones between the welds were then opened up for welding. A final layer over all the welds was then made to level off the surface. Having sunk the barriers below the depth of the cracks any further cracking that took place is confined to the zones between the barriers, thus suitably protecting the main weld.—J. P. S.

Quality Control of Spot Welded Assemblies. A. J. Hipperson. (*Welding Metal Fab.*, 1952, **20**, Mar., 99–102).

The Practical Testing of the Cohesive Strength and Weldability of Steels. W. A. Felix. (*Welding*, 1952, **31**, Feb., 105s–111s). A description is given of testing methods employed in a large Swiss engineering works for investigating the suitability of a steel for use in highly stressed welded structures.—U. E.

Thoriated-Tungsten Electrodes—Their Welding Characteristics and Applications. G. J. Gibson and R. O. Seitz. (*Welding J.*, 1952, **31**, Feb. 102–108). Thoriated-tungsten electrodes were first used a year ago for welding aluminium with the tungsten-arc process. Its characteristics are also suitable for all D.C. straight polarity, inert-gas-shielded tungsten-arc welding, including stainless steel, copper, carbon steel, and titanium.—U. E.

Seventy Years of Welding. H. J. Thompson. (*Trans. Inst. Welding*, 1951, **14**, Dec., 195–200). This is a review of welding methods applied to products such as chemical plant, transport, tankers, refuelling equipment, and aircraft components involving a wide variety of materials ranging from 22 S.W.G. up to 2 in. thick.—U. E.

Manufacture of Large-Diameter Pipe. (*Welding Metal Fab.*, 1952, **20**, Feb., 49–53). The laying of a pipeline for natural gas from the Gulf of Texas to New York City is described. Sections of the pipe 30 in. in dia. were joined successfully by the submerged-arc welding process.—U. E.

Types of Electrode Required. A. N. Shashkov. (*Avtog. Delo*, 1948, No. 9, 9–11). [In Russian]. The conditions under which arc-welded seams are produced and the properties required of them in modern industrial techniques are considered, and a systematization is attempted of electrode cores and coatings in relation to the weldability and functions of steels.—S. K.

Deformation of a Blast-Furnace Shell During Welding. V. I. Mel'nik and R. G. Shneiderov. (*Avtog. Delo*, 1948, No. 9, 6–9). [In Russian]. The effect of deformation in weld seams on the design of large welded structures is considered, and an account is given of measurements of deformation taking place during the arc welding, with slag and gas shielding, of a blast-furnace shell consisting of plates 24, 30, and 32 mm. thick. The lateral shrinkage of a vertical seam varied along its length, the greatest excess over the mean value of approximately 2·4–2·6 mm. occurring in the middle portions. The lateral shrinkage in horizontal (ring) seams varied from 2·8 to 3·1 mm.—S. K.

Welding a Blast-Furnace Shell. B. L. Sheinkin and V. L. Tsegel'skii. (*Avtog. Delo*, 1948, No. 9, 1–5). [In Russian]. A detailed account is given of the assembly, welding, and testing of the shell of a blast-furnace at "Zaporozhstal." Multiple-bead arc welding with coated electrodes was used, the seams being hammered while hot. The assembly and welding required, respectively, 24 and 44 days. Radiographic inspection of seams was carried out and control plates, welded at frequent intervals, were subjected to tensile and bend tests. From experience gained it is strongly recommended that the shell should be assembled from prewelded sections of the largest size permitted by the available cranes.

MACHINING AND MACHINABILITY

Increasing Productivity in Production Machining. M. Field and N. Zlatin. (*S.A.E. Quarterly Trans.*, 1952, **6**, Apr., 196–212). Methods of increasing production by: (1) Reducing the time for performing the handling, clamping, rapid traversing, and other machine functions necessary to bring the workpiece to the tool; and (2), the reduction in the time necessary actually to machine the metal are considered.—P. M. C.

Conserve Diamond Bort and Cut Hard-to-Machine Materials with New Machining Processes. (*J. Met.*, 1952, **4**, Apr., 378–380). The potential values of new processes for machining and grinding, developed with the object of conserving diamond bort, are evaluated. The techniques considered include the electrolytic, electro-sparking, electro-arcing, and ultrasonic processes, and various combinations of the four.—G. F.

Heavy Machining Operations in Rolling Mill Construction. (*Machinery*, 1952, **80**, Jan. 31, 191–194). Methods employed by Davy and United Engineering Co., Ltd., Sheffield, are described.—E. C. S.

New Method of 'Machining' Hard Metals. J. S. Roller. (*Machinery*, 1952, **80**, Feb. 21, 322–323). In 'Method X,' developed by the Method X Co. of Philadelphia, an affiliate of Firth Sterling Steel and Carbide Corp., metal is removed from any electrically conductive material by means of an electric spark discharge.—E. C. S.

Arc Machining Makes Hard-to-Cut Jobs Easy. H. V. Harding and V. E. Matulaitis. (*Machinist*, 1952, **96**, Apr. 5, 514–519). The development of arc machining processes is traced with special reference to the work of the Elox Corp. of Michigan. It can be used for removing broken-off taps. The principles, tools, and methods involved in the process are described in detail.—E. C. S.

Cutting Machine for Hard Metallic Materials. (*Biuletyn Informacyjny Glownego Instytutu Metalurgii*, 1952, No. 2, 8: *Hutnik* (Katowice), 1952, **19**, No. 2). [In Polish]. An anode cutting machine is briefly described. The cutting tool, an iron disc, is the cathode, whilst the anode is the object machined. Sodium silicate solution (sp. gr. 1·32) is used as an electrolyte.—V. G.

Russians Machine Bearing Balls Electro-Mechanically. N. A. Pankratov, B. P. Gofman, and M. M. Feldman. (*Promyshlennaya Energetika*, 1950, No. 10, 10–11: *Iron Age*, 1952, **169**, Mar. 13, 98–99). At the State Bearing Works in Russia balls are machined electromechanically by rolling between charged upper and lower discs. The lower disc rotates at 500 to 600 r.p.m. and micro-arcs soften the ball surface and the rotating disc throws off the softened metal particles. The metal is removed at up to 0·0012 in./min., the rate varying directly with the voltage. The slightly pitted and decarburized surface of the ball is removed by hard lapping. The balls can be fed and removed from the machine automatically, permitting high production rates.—A. M. F.

Nitrogen-Alloyed Cast High-Speed Steel. V. I. Prosvirin and I. F. Zudin. (*Azot v Stali*, 1950, 161–168). The manufacture of cast tools from nitrogen alloyed high-speed steel, and their performance were investigated. It is claimed that: (1) The manufacture of cast tools is simpler and less expensive than that of forged tools; and (2) the service life of cast tools of low-tungsten high-speed steel alloyed with nitrogen is longer than that of forged high-speed steel tools.—V. G.

Manufacture and Use of Graphite Tool Steels Show Vast Progress. A. F. Sprankle. (*Iron Age*, 1952, **169**, Feb. 28, 100–103; Mar. 13, 106–110). The machinability of graphitic tool steels containing about 0·40% of free graphite is shown to be much superior to that of comparable tool steels. Best machinability is obtained, with carbon in the spheroidized condition, at a hardness range of 197 to 229 Brinell. Tests have also shown that this type of tool steel will take almost twice the load of normal die steels without galling.—A. M. F.

New Machining Techniques Evaluated. G. Elwers. (*Iron Age*, 1952, **169**, Mar. 20, 103–105). Four new machining and grinding processes have been evaluated by the National Research Council. Electrolytic, electro-arcing, electro-sparking, and ultrasonic processes show promise for such applications as carbide tool grinding, titanium jet-engine disc machinery, and rifling gun barrels.—E. M. F.

Analysis of Changes in the Roughness of Machined Surfaces. M. M. Tenenbaum. (*Zavodskaya Laboratoriya*, 1950, No. 2, 204–207). [In Russian]. It is pointed out that, for the study of wear, it is necessary to know not only the extent of surface roughness before and after the test, but also the nature of its change. A profilographic apparatus for doing this is described, and some results are presented. On the basis of results obtained, improvements in the wear-resistance of steel-babbitt contact surfaces are outlined, and further applications of this technique are considered.—S. K.

Trepanning Makes Holes Faster. F. W. Lucht. (*Iron Age*, 1952, **169**, Apr. 3, 132–134). For deep holes, trepanning can be as much as 95% faster than drilling. This is partly because cutting is faster with carbide-tipped tools, but mostly because less of the metal is made into chips. Holes up to 30 or 40 ft. in length and 4½ in. dia. can be held to within a few thousandths of an inch on both concentricity and diameter. Cutting fluid pressures of at least 175 lb./sq. in. and considerable power are required to take advantage of the cutting ability of carbide tools.—A. M. F.

CLEANING AND PICKLING

Wet Blasting Performs Many Cleaning and Finishing Operations. J. L. Everhart. (*Mat. Methods*, 1952, **35**, Apr., 98–100). Wet blasting, liquid impact blasting, or liquid honing, as the process is variously called, consists of blasting with a suspension of abrasive in a liquid (usually water). Extremely fine abrasives (down to 5000 mesh) can be used, without danger of packing. The abrasive can be varied from silicon carbide to soft nut shells or corn husks. Applications of the process are briefly described.—P. M. C.

Cleaning Work with the Aid of Ultrasonic Vibration. C. B. Fay. (*Machinery*, 1952, **80**, May 15, 853–855). The 'ultrasonic' cleaning machine developed by Schick engineers and built by the General Electric Co., is described. In this machine a high-frequency electric current is converted into high-frequency vibration of the solvent in the cleaning tank. Improved cleaning at higher production rates is obtained and the cost of cleaning has been reduced by as much as 58%.—E. C. S.

Smooth Finish for Strip—Moving Abrasive Produces It.

S. L. Johnson and R. G. Hall. (*Steel*, 1952, **130**, Mar. 3, 82–83). A process for finishing steel strip consists in scouring both sides simultaneously with progressively fed coated abrasive paper. The result is a uniform surface over the entire length and width of the strip. Abrasives used are aluminium oxide and silicon carbide; they may be applied either dry or with water or oil. Another use is for scouring where black chromium oxides exist, to facilitate subsequent pickling.—A. M. F.

The Preparation of Metallic Surfaces for the Application of Coatings. S. M. Anderson. (Australian Inst. Metals: *Australasian Eng.*, 1952, Jan. 7, 68–70). The removal of dirt and soil of an oily nature is described with particular reference to organic solvents and alkaline cleaners. The removal of scale, oxides, and corrosion products by mechanical means, ordinary pickling, and electrolytic pickling is next dealt with, and the author concludes with a few comments on the production of good surface finish by mechanical and electrolytic polishing.

Polishers and Polishing. C. Harris. (*Metal Ind.*, 1952, **80**, Apr. 18, 308–310; Apr. 25, 326, 327). The author emphasizes the craftsmanship and experience necessary for good polishing. Equipment and methods are outlined.—P. M. C.

On the Mechanism of Electrolytic Polishing of Metals. W. J. McG. Tegart and R. G. Vines. (Australian Inst. Metals: *Australasian Eng.*, 1952, Jan. 7, 70–72). The theories for the mechanism of electropolishing are briefly reviewed, and the authors then propose the unifying hypothesis that the viscous reaction products control the levelling action, and the oxide layer controls the micro-smoothing action. (15 references.) P. M. C.

PROTECTIVE COATINGS

The Development of Cladding. W. Engelhardt. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1940, **8**, Sept., No. 7, 150–160). In cladding (or plating) in order to obtain a satisfactory bond between two metals or alloys it is essential to attain a resonance between the atomic bands of the two metals at the surface. It is necessary to have both metals at one temperature and to have the atomic mobility large enough for resonance to occur; diffusion can then take place to an appreciable extent. The limitations of cladding by welding, cast plating (dipping), and electroplating are considered together with present and future considerations of cladding. Diffusion is essential to obtain a strong bond. The welding of plated materials, plating tubes, and machine parts, plating without waste, and plating impure materials are discussed.—R. J. W.

Selecting Hard Facing Materials to Resist Impact, Heat, Friction, Abrasion. H. S. Avery. (*Product Eng.*, 1952, **23**, Mar., 154–159). The effects of impact, heat, friction, and abrasion on hard-facing alloys are explained and the choice of a suitable material is aided by a number of tables which compare the properties and wearing qualities that can be expected. The choice and selection of the base material is also of importance.—A. M. F.

Chromium Plated Piston Rings. (*Automobile Eng.*, 1952, **42**, May, 181, 182). Brief details are given of manufacturing techniques, bedding-in requirements, and service results for the newly developed 'Vacrom' piston ring. Chromium deposits of 0·003 in. for petrol engine rings, and 0·005 in. for diesel engines have resulted in very definite improvements in cylinder bore life.—P. M. C.

Progress in the Sphere of Chromizing, Especially Mass-Chromizing and the Problems of Composition, Control and Supervision Closely Associated with it. R. Bilfinger. (*Metallwirtschaft*, 1943, **22**, Oct. 20, 466–472). The general properties and the range of uses of hard chromium plating are first reviewed. The advantages of mass-chromizing, such as saving of current and chromium, and the methods and devices used to effect this are discussed, and diagrams given of the electrode arrangements. The composition of the bath, the reactions which take place, and the dependence of the current output on the concentration of various acids (including chromic, sulphuric, hydrofluoric, and fluosilicic acids) are dealt with. Closer control of the bath composition can be obtained by means of new analytical methods.—R. J. W.

The Present Position and Future Prospects of Hard Chromium Plating. P. Cüppers. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1940, **8**, Dec., No. 10, 234–239). The preliminary condition for further development of hard chromium plating is that numerous basic questions be clarified. In particular, the factors have to be discovered which determine the formation of a good coating. The causes of the failure of chromium plating on cast iron have yet to be investigated.—R. J. W.

Non-Stop Plant for Hot-Dip Galvanising of Wire. (*Product Finishing*, 1951, **4**, Dec., 76–79). The new plant of Richard Johnson and Nephew, Ltd., Manchester, for the continuous galvanizing of steel wire is described.—J. P.

The Flux Reactions in Hot Dip Galvanising.—I. H. Bablick, F. Götzl, and R. Kukaczka. (*Metallwirtschaft*, 1943, **22**, Oct. 20, 463–466). The various types of flux for hot-dip galvanizing are reviewed and the methods of using them described. The chemical composition, properties, supply, and structure of the fluxes are considered together with the chemical reactions which take place. The parts played by the NH_3, HCl, and H_2O dipoles and the various ions produced are described. Finally the reactions of the fluxes which take place in zinc baths containing aluminium are discussed.

A Theory of the Mechanism of the Formation of Zinc Coatings during Galvanizing. H. Bablik, F. Götzl, and R. Kukaczka. (*Sheet Metal Ind.*, 1952, **29**, Feb., 173, 174). The authors postulate that the thickness of an iron–zinc layer depends upon the magnitude of the iron reaction surface. They also believe that the area available for reaction is affected by alloying elements. The effects of carbon, nitrogen, silicon, and titanium are quoted.—P. M. C.

The Hot-Dip Galvanizing of Structural Steel Sections. R. A. Painter. (*Proc. Inst. Elect. Eng.*, 1952, **99**, II, Feb., 39–45). The methods of protecting mild steel from dissolution by electrochemical action are described. Spraying and the 'wet' or 'dry' hot-dipping of structural steel components with zinc are discussed. A brief description of the metallurgical construction of the zinc coat, together with information on its expected life is given. Details of the process, methods of quality control and advice on the after care of the finished product are included.—H. D. W.

Continuous Electro-Galvanizing. (*Elect. Rev.*, 1952, **150**, Jan. 4, 3–7). A detailed description is given of the continuous electrogalvanizing plant operated by Maclean and Co., Ltd., for the protection of steel window frames. Cathodic and anodic pickling in sulphuric acid is followed by plating with 99·99% pure zinc. The lifting, pickling, and plating equipment is operated electrically, the drying ovens being gas fired.—H. D. W.

South American Wire Galvanizing Plant—Suggestions for Improved Technique. (*Wire Ind.*, 1952, **19**, Feb., 135–137). A South-American firm has made a request for advice on the modernization of their wire galvanizing plant. The paper contains a description of the existing plant, points from the enquiry, and the advice given. The last deals mainly with simplification of design and application of usual English practice.—J. G. W.

Differential Thickness Coating on Electrolytic Tinplate. S. S. Johnston. (*Iron Steel Eng.*, 1952, **29**, May, 72–75). The author describes methods by which economy in the use of tin can be achieved. Methods adopted by the Weirton Steel Co. are examined including that by which one side of the sheet is given a thicker layer of tin than the other.—M. D. J. B.

Control Addition Agent Vital in Lead–Tin Plating. J. B. Mohler. (*Iron Age*, 1952, **169**, Feb. 7, 139–141). Close control over addition agents is needed for best results in lead–tin plating. Small amounts of copper, antimony, or arsenic increase strength and fatigue resistance. Gelatin or glue in the bath give a fine-grained deposit. Resorcinol is a useful secondary addition agent.—A. M. F.

Testing the Bond in Composite Cylindrical Castings (Steel–Copper Alloys). G. Vogt. (*Metallwirtshaft*, 1943, **22**, Dec. 20, 553–556). The types of bonding used to stick steel to copper alloys are either fusion or diffusion bonding. The bonds can be tested by: (1) The ringing test, in which a clear sound must be emitted by the bonded material when struck; (2) the boiling oil or milk-of-lime test, in which cracks are shown up; (3) microscopic investigations; (4) stretching and twisting tests; (5) the thermo-colour method; and (6) investigations of the mechanical strength and shearing properties of the bond.

New Method Tested for Cladding Bullet Jackets. S. Tour. (*Iron Age*, 1952, **169**, Mar. 27, 108–110). A new method for cladding copper to steel has been tested but is not yet in commercial production. Molten copper or gilding metal is poured on to a steel slab with the aid of a methyl borate flux; side walls welded on hold the metal on the steel until it solidifies. The composite slab is then rolled out. Tests have

indicated that there is an excellent bond between the two metals with the iron thoroughly dispersed in a finely divided uniform manner.—A. M. F.

Low Cost Black Oxide Finish Produced on Steel by Chemical Dip Method. A. J. Mitchell. (*Mat. Methods*, 1952, **35**, Mar., 92–95). Black oxide finishes are attractive, durable, corrosion resistant, and suitable for a variety of applications, including machine parts, bearings, gauges, and aircraft engine components. Several methods are available; the Carbonia, Browning, and heat-treatment methods are briefly outlined, and the aqueous alkali-nitrate method is described.—P. M. C.

Combination of Metals and Non-Metals. U. R. Evans. (Swansea Chemical Soc.: *Metal Treatment and Drop Forg.*, 1952, **19**, Apr., 172). The formation of oxide, sulphide, and iodide films on metals immersed in suitable solutions is discussed with particular reference to the passage of the metal or non-metal through the film.—P. M. C.

Aluminium Electroplated on Steel from Fused Salt Bath. F. R. Collins. (*Iron Age*, 1952, **169**, Jan. 17, 100–101). Aluminium has been successfully electroplated on steel from a fused aluminium-chloride/sodium-chloride salt bath. The plate is uniform and no interfacial layer of Fe–Al alloy occurs. Aluminium-coated steels show high resistance to rusting in industrial, sea-coast, and humid atmospheres. The coating is free from continuous pores.—A. M. F.

The Use of Ethyl Silicate in Providing Coatings of Aluminium on Steel. G. Tolley. (*J. Applied Chem.*, 1951, **1**, Feb., 86–90). The doping of sprayed aluminium with ethyl silicate gives a heat-resistant coating which needs no heat-treatment before putting into service. This coating is compared with aluminizing and the protection given by these two coatings to mild steel from 700 to 950° C. is reported.—R. A. R.

The Coating of Steel with Aluminium. D. P. Moses and G. G. Popham. (*Metallurgia*, 1952, **45**, Feb., 70–74). Various methods of coating steel with aluminium are reviewed. Spraying, calorizing, and heat-treatment of coatings, and hot dipping, cladding, casting, electroplating, and vapour-reaction processes are mentioned.—T. E. D.

The Protection of Steel by Sprayed Aluminium. W. E. Ballard. (*Electroplating*, 1951, **4**, Dec., 395–399). A mechanism is suggested for the formation of rust stains on freshly prepared aluminium-sprayed steel, and methods to prevent it are described. These stains are not indicative of early failure. While it is worth while making efforts to avoid staining, its relative unimportance should be realized and the stains covered by painting.—J. P.

The Electrodeposition of Copper–Cadmium Alloys from Cyanide Solutions. E. E. Longhurst. (*J. Electrodep. Tech. Soc.*, 1950, **26**, 71–89). On the basis of preliminary experiments, a solution of composition corresponding to 0·3 *M* cuprous cyanide, 0·025 *M* cadmium cyanide, and 0·71 *M* sodium cyanide was chosen for detailed study. Copper and cadmium codeposit as homogeneous alloys in the range 28 to 52% copper, but as alloys visibly heterogeneous outside this range.—R. L. B.

The X-Ray Structure of Speculum Electrodeposits. H. P. Rooksby. (*J. Electrodep. Tech. Soc.*, 1950, **26**, 119–124). The investigation concerned electrodeposits of speculum, containing about 42 wt.-% of tin, on copper. X-ray examination showed the deposits to possess either a metastable cubic near-gamma crystal structure or one closely approaching that of the hexagonal eta phase, Cu_6Sn_5. Heat-treatment at as low a temperature as 200° C. modifies the structure of the cubic form to that of epsilon.—R. L. B.

Further Work on the Electrodeposition and Properties of Speculum. P. S. Bennett. (*J. Electrodep. Tech. Soc.*, 1950, **26**, 107–118). Speculum electrodeposited by the conventional solutions normally requires subsequent mechanical polishing to obtain a bright lustrous finish. By the addition of organic brighteners to the plating bath, in conjunction with small amounts of lead, the author produced bright speculum electroplate. Close control of all variables of the process is necessary, and the current density over the surface of the workpiece must be as uniform as possible.—R. L. B.

Organic Finishes for Metal Surfaces. (*Product Finishing*, 1952, **5**, Feb., 69–75). The properties, methods of application, and uses of the following types of finish are discussed: Bituminous, varnish, oleoresinous, cellulose, vinyl and acrylic lacquer, and alkyd, urea, melamine, styrene, phenolic, and silicone base enamels.—J. P.

Silicone Coatings Protect Metals Against Severe Service Conditions. C. E. Arntzen and R. D. Rowley. (*Mat. Methods*, 1952, **35**, Jan., 82–84). Brief details are given of the heat resistance, weathering properties, and resistance to chemical attack of silicone finishes.—P. M. C.

Metal Spraying. (*Product Finishing*, 1952, **5**, Feb., 40–47). The methods employed by Metallization, Ltd., Dudley, for the application of metal coatings for protection and repair work by the wire melting and spraying pistol are described. The type of pistol for manual operation and the recently developed automatic plants for spraying tubes and girders are illustrated.—J. P.

Production Experience Proves Diaphragm Plating. R. L. Redmond. (*Iron Age*, 1951, **168**, Dec. 13, 132–133). High-speed copper-plating tanks have been equipped with two layers of 11-oz. fabric mounted on rubber-covered frames between the cathode and workpieces to minimize pits and bumps caused by insoluble particles. During plating, the solution is pumped continuously from the anode compartment through an efficient filter and back to the cathode. Higher current densities can be satisfactorily used.—A. M. F.

POWDER METALLURGY

Method of Producing Iron Powder. N. N. Alekseev. (*Zavodskaya Laboratoriya*, 1950, No. 2, 256). [In Russian]. A brief note is given on the preparation of iron powder by heating ferric oxide powder at 750–800° C. with transformer oil under reduced pressure.—S. K.

Determination of Particle Size in the Sub-Micron Range. Y. Schubert and B. Kopelman. (*Powder Met. Bull.*, 1952, **6**, Apr., 105–109). Size determination is important for iron powders below 1000 Å. dia., since magnetic properties are influenced by size. Comparative tests were made between methods of determining particle size depending on X-ray line broadening of the diffracted beam, and the adsorption of a monomolecular layer of nitrogen on the particles (the B.E.T. method). Reasonably good agreement was obtained, indicating that either method is suitable for ultra-fine iron powder in the range 50–400 Å. dia.—K. E. J.

The Plus and Minus of Making Your Own Powder Metal Parts. J. L. Bonanno. (*Mat. Methods*, 1952, **35**, Apr., 101–105). The author discusses costs, tool and laboratory facilities, and the economic aspects of setting up a powder-metallurgy department for the mass production of small parts.—R. A. R.

Rules for the Construction and Use of Sintered Iron Bearings. W. Schroeder. (*Technik*, 1952, **7**, Apr., 181–188). The author reviews the properties, design, manufacture, and use of sintered iron bearings.—J. G. W.

Sintered Metals Based on Iron, with Special Reference to Bearing Metals. O. H. Hummel. (*Metallwirtschaft*, 1943, **22**, Mar. 30, 206–210). Various types of sintered irons are first classified and their more important uses discussed. The properties of some sintered metals make them eminently suitable for use as gear wheels and bearing surfaces such as rings and bushes. The sintered irons are classified according to their strength. The relationship between porosity and lubrication is established and the effect of machining and welding described.—R. J. W.

PROPERTIES AND TESTS

Modern Testing Machines. (*Machinery Lloyd, European Edition*, 1952, **24**, May, 65–71). Seven testing machines are described: (1) A universal model, suitable for tensile, bending, or compression tests without modification; (2) a machine for compression tests, such as are used for building materials; (3) a universal machine larger than the others, built in 50- and 30-ton models each of which is hydraulically operated; (4), (5), and (6) three creep-testing machines.—B. G. B.

Inspection and Measurements in Industry. D. J. Stern. (*J. S. African Inst. Mech. Eng.*, 1952, **1**, Mar., 225–256). A review of the recent developments in inspection and testing methods is presented. It includes sections on quality control, the testing and measuring of the mechanical properties of solids, tolerances and measuring, and non-destructive testing. (30 references).—T. E. D.

Fundamentals of a Test Method. G. L. Peakes. (*A.S.T.M. Bull.*, 1952, Jan., 57–61). After the test has been applied to a group of product units, the '*F* ratio' (variance of product divided by the variance of test) is computed and its significance obtained from tables. If the *F* ratio is not significant the test should be abandoned; more tests should be made if it is near the significant level; if definitely significant then the significance is treated by statistical methods.—B. G. B.

Tensile Testing of Cast Iron. G. Meyersberg. (*Gjuteriet*, 1952, **42**, May, 71–82). [In Swedish]. Previous research by Griffith and others established that faults distributed in the structure of materials, best described as fine cracks between the atom planes, seriously affect tensile strength and cause it to decrease as material volume increases. The effect of this factor, called 'volume sensitivity,' was investigated. Tests are described to formulate sensitivity indices for test pieces, similar in composition, which were subjected to different loads under varying stress conditions. They included the transverse test (where sensitivity was lowest), cutting by special wedges (where it was highest), and the torsional grip test (in which it was somewhat lower than in the wedge method). The skin effect of graphite formations could cause variations in tensile strength, which increased in inverse proportion to diameter.—G. G. K.

Tensile Tests of Internally Notched Plate Specimens. S. T. Carpenter and W. P. Roop. (*Welding J.*, 1950, **29**, Apr., 161s–183s). In Part I the physical behaviour at various temperatures of a large number of 12-in. wide ¾-in. thick steel-plate specimens was investigated. The specimen contained a centrally located internal notch 3 in. wide terminating with a jeweler's hacksaw cut ⅛ in. long and 0·010 in. wide. All tests were made with tension loading applied in the direction of rolling. Transition temperatures were determined. It was found that for all steels tested the ratio of average maximum loads for specimens failing in 100% shear to those failing in 0% shear was practically constant, but the ratio of average energy was variable for the separate steels. A vibrational phenomenon was observed in measuring strains for specimens that were later found to be brittle. In Part II the effects of shape and metallurgy on the energy absorbed by the specimen were studied.—U. E.

The Bollenrath Dilatometer in Operation. A. Metz. (*Metallwirtschaft*, 1943, **22**, Dec. 20, 559–561). The Bollenrath dilatometer has been developed, using different accessories, for routine use. By combining a suitable galvanometer with the dilatometer it is possible to measure the absolute expansion curve without a quartz comparator specimen, and thus to follow higher heating and cooling rates. Besides this, the measurement of a thermo-differential curve similar to the Saladin system is possible. By the use of a recording cassette, temperature–time curves can be obtained. It can be applied to measure the change of electrical resistance with time and temperature.—R. J. W.

Axial Tension Impact Tests of Structural Steels. W. H. Bruckner and N. M. Newmark. (*Welding J.*, 1950, **29**, Apr., 212s–216s). Tensile impact tests were made with specimens of two killed steels and a rimming steel, at different levels of initial energy. It is shown that, for the killed steels, the transition temperature decreased with decreasing initial energy; but for the rimming steel there was little change in transition temperature with a change in initial energy of the impact. Charpy impact tests were made with specimens of a semi-killed steel which showed in the previous tests a considerable change in transition temperature when tested in axial tensile impact.—U. E.

Tension Impact Testing. A. C. Vivian. (*Structural Eng.*, 1952, **30**, June, 121–128). Two testing machines are described. The first machine pulls a tension bar apart and determines the ultimate tensile strength and the ductility of the bar under the same rate of impact loading as the Izod test. The second machine is designed to produce an autographic load-extension diagram of a tensile bar at either slow or at 'static' rate of loading. The results of tests carried out on the tension-impact machine are given and are compared with those obtained with static tests.—B. G. B.

Transition Temperature of Ship Plate in Notch-Tensile Tests. E. M. MacCutcheon, C. L. Pittiglio, and R. H. Raring. (*Welding J.*, 1950, **29**, Apr., 184s–194s). This is a detailed study of steels under new specifications used in ship construction together with some experimental steels, and their ductile-to-brittle transition temperatures were determined. It was found that the transition temperature as determined by the 12-in. wide specimens is essentially the same by either the absorbed-energy or the fracture-appearance criterion.—U. E.

The Notch Toughness Test of Henri Schnadt. W. P. Roop. (*A.S.T.M. Bull.*, 1952, Jan., 61–64). A theoretical discussion of the test is given and the lines of future development suggested are: A scale of test pieces is set up in which a series of degrees of triaxiality is established. The material proposed for use is placed on this scale according to its capacity for ductile behaviour. This capacity on the part of the metal is matched against a requirement on the part of the service structure. The condition to be satisfied is that the characteristic value of triaxiality associated with the structure shall be lower than the critical value associated with the metal. A number of reservations, with respect to the Schnadt method, which must be noted, are given.—B. G. B.

Materials Mechanics. E. Siebel. (*Z.V.d.I.*, 1952, **94**, June 1, 465–471). The author applies modern ideas of metal physics and plasticity to practical problems of the strength of materials, when tensile stresses are present. He deals with ductile and brittle fracture, the effect of hydrostatic compression and tension, notches, and temperature.—J. G. W.

New Method of Determining and Evaluating the Plasticity of Metals and Alloys. I. K. Antsyferov. (*Zavodskaya Laboratoriya*, 1950, No. 2, 224–230). [In Russian]. From a critical examination of the results of large-scale and laboratory determinations of the plasticity of steel by Chizhikov's methods, the following conclusions are drawn: (1) Plasticity tests should always be made on cast specimens; (2) specimens should be at 900–1200° C., with no, or very little, scale; (3) specimens should be large enough to avoid the high plasticity shown by small specimens; (4) specimen dimensions should be in accordance with the full-scale process under consideration; and (5) the appearance of the first lateral cracks indicates the loss of plastic properties.—S. K.

Plastic Twisting of Cylindrical Bars. L. G. Afendik and V. G. Bessonov. (*Zavodskaya Laboratoriya*, 1950, No. 2, 197–204). [In Russian]. An account is given of an investigation on deformations during the twisting of cylindrical bars of plastic materials. The complicated nature of the relationship between the results of tensile and twisting tests is pointed out, and a procedure for specimens of low-carbon steel and grey cast iron is described. With specimens having a neck 10 mm. in dia., the maximum twisting angle for the cast iron was $\frac{1}{164}$ of that for steel. Various equations for calculating deformations during plastic twisting are given, the different results obtained being compared.—S. K.

Delayed Fracture of Metals under Static Load. N. J. Petch and P. Stables. (*Nature*, 1952, **169**, May 17, 842–843). In glass delayed fracture has been attributed to gas adsorption on a Griffith crack surface. A similar mechanism is put forward for hydrogen embrittlement of steels, only differing in that the adsorption atoms are supplied from solution in the steel.

Design Factors for Stress Concentration—Flat Bars with Multiple Notches. A. J. Durelli, R. L. Lake, and E. A. Phillips. (*Machine Design*, 1951, **23**, Dec., 165–167). The results of an investigation of the stress concentrations caused by semi-circular notches in a bar under axial load are presented.

Some Observations on the Determination of Residual Stresses in Cylindrical Metal Bodies by Sachs' Boring Method. R. A. Dodd. (*Metallurgia*, 1952, **45**, Mar., 109–114). An experimental technique, applicable to solid cylinders or thick-walled tubing is described. It eliminates: (*a*) Errors in the measured strains using electrical resistance gauges; and (*b*) errors due to the introduction of extraneous residual stresses during machining of the specimen and enables the tests to be carried out more rapidly. Comparisons are made between stresses obtained by Sachs' and X-ray methods, and the theoretical aspects of the method are discussed.—B. G. B.

Strain Gauges. T. W. Bunyan. (*Eng. Insp.*, 1952, **16**, Spring Issue, 2–14). The principle of the electrical resistance strain gauge is outlined, and the procedure for cementing them in operating positions is described. Instrumentation and methods of recording static and dynamic strains are discussed.

Concerning the Stresses which Occur During Nitriding. J. Geiger. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1942, **9**, July, No. 8, 161–164). This investigation showed that compressive stresses up to 6500 kg./sq. cm. are produced during nitriding. They fall to zero extremely rapidly and cause unimportant tensile stresses in the non-nitrided part. Three different methods were used to measure the stresses: (1) Boring cylindrical bodies; (2) slitting a nitrided ring; and (3) cutting a cylindrical hollow body into long strips and measuring the curvature.—R. J. W.

Investigation of Material to Establish the Cause of Explosion of a Fireless Locomotive Following a Flange Fracture. H. Biegler. (*Technik*, 1952, **7**, Mar., 131–134). Surface and radiographic examination of the flange provided convincing

evidence that corrosion was primarily responsible for the failure.—J. G. W.

Possible Applications of Fatigue Testing Machines with Resonance Drive. M. Russenberger. (*Z.V.d.I.*, 1952, **94**, Apr. 21, 314–318). The various working principles of resonating testing machines are explained, followed by a description of the Amsler universal pulsator and of its applications.

A Small French Fatigue Testing Machine. H. Oschatz. (*Metallwirtschaft*, 1943, **22**, Dec. 20, 558–559). The development and construction of a French vibrating testing machine is described. Detailed cross-sectional diagrams are shown to illustrate the three ways in which this can be used to apply: (1) Revolving bending oscillations; (2) tension–compression oscillations; and (3) twisting oscillations. The fatigue testing frequency of this machine is 120 vibrations/min.—R. J. W.

Bending Oscillations of a Specimen under Pulsating Axial Load. E. Mettler. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1940, **8**, Feb., No. 1, 1–15). The differential equation of the problem is first developed and the mathematical treatment of a Mathieu-type differential equation given. Then follows a general discussion of the solution and a calculation of the characteristic exponents. A description of the character of the oscillations leads to a calculation of the conditions necessary for resonance to occur, both with and without damping. A numerical example is given.—R. J. W.

How to Design for Repeated Loads. R. L. Templin and E. C. Hartmann. (*Iron Age*, 1952, **169**, Mar. 27, 98–101). The factors affecting fatigue life are enumerated and design conditions to improve this life are given.—A. M. F.

Torsional Fatigue Failures. Part II. J. O. Almen. (*Product Eng.*, 1952, **23**, Mar., 168–174). Analytical studies of fatigue fractures in torsion-bar springs for military vehicles show that, in spite of inherent planes of weakness, torsional fatigue failures are caused by, and develop normal to, the tensile component of the applied stress. Data bearing on the characteristics of torsional failures obtained from fatigue tests of torsion bars subjected to variations in processing are also given.—A. M. F.

The Torsion Test for Wire. J. G. Walford. (*Wire Ind.*, 1952, **19**, Mar., 233–235, 280). An account is given of tests on high-carbon steel rope wires, which were performed with the aim of discovering whether existing torsion test specifications are sufficiently rigid, and whether the results of the tests are influenced by the length of the specimen and the tension applied to it. Of existing specifications only the German ones appear to be satisfactory in this respect. Both specimen length and tension may affect the results greatly.—J. G. W.

The Compression of the Surface Layer by Pressing. O. Föppl. (*Metallwirtschaft*, 1943, **22**, Dec. 20, 556–557). When applying surface pressure to improve the fatigue properties of a material, a surface layer from 0·1 to 1·0 mm. thick must be compressed. The processes by which this surface layer is compressed by steel grit or by the pressure of rolls are discussed. In the machining of round material the effect of the rate of feed on the surface quality is described. Finally, practical considerations of compressing the surface and of surface finish are given.—R. J. W.

Improved Method for Estimating Fatigue Life of Bevel and Hypoid Gears. W. Coleman. (*S.A.E. Quarterly Trans.*, 1952, **6**, Apr., 314–331). The method is claimed to offer a means of comparing various tooth forms and gear mountings. It consists of making a layout in the mean normal section of the tooth, and of calculating the tensile stress in the fillet when the maximum load is applied at its highest position on the tooth.—P. M. C.

Working Stresses for Helical Springs. O. G. Meyers. (*Machine Design*, 1951, **23**, Nov., 135–138). Maximum permissible design stress is not constant for a given spring material but varies with wire diameter, stress range, and required number of operating cycles. The application of stress/number-of-cycles curves derived from rotating-beam fatigue tests is discussed.—E. C. S.

Biaxial Fatigue Tests on Flat-Plate Specimens. R. U. Blaser, J. T. Tucker, jun., and L. F. Kooistra. (*Welding J.*, 1952, **31**, Mar., 161s–168s). A description of a method of materials testing simulating the state of stress encountered in pressure-vessel service is given. In the test, the rectangular plate is freely supported on the edges, while it is uniformly loaded on one side by oil pressure. Cyclic conditions are set up by periodic pulsation of the oil pressure. An experimental stress analysis is given for a $\frac{3}{4}$-in. thick specimen, and methods of detecting initiation of rupture are discussed as well as the final appearance of the fatigue fracture.—U. E.

Fatigue Fractures inside Shrunk Joints in Crankshafts. K. Gleitz. (*Technik*, 1952, **7**, Mar., 107–112). Fatigue failures of built-up crankshafts of gas engines are described and modifications to crankshaft design are considered. The repair of fractured shafts by thermit welding is discussed.—J. G. W.

Statistical Design of Fatigue Experiments. W. Weibull. (*J. Appl. Mech.*, 1952, **19**, Mar., 109–113: *Tekn. Tidsskr.*, 1952, **82**, Feb. 19, 157–161). In order to study the relationship between size of test rod and its fatigue limit, the author has assumed an exact relationship between load S and life N of the sample, which can be expressed as $S - E = A(N + B)^{-m}$ in which E is the fatigue limit and A, B, and m are parameters which may be determined graphically or mathematically. The paper derives parameter values for four or more load groups, the optimum distribution of tests in the load groups, and choice of load size.—G. G. K.

A Large Installation of Machines for Study of Hardness. (*Bulletin Annuel Association des Industriels de Belgique*, 1952, No. 62, 21–32). A description is given of several hardness testing machines, their operation and the type of work carried out.—B. G. B.

Heat Treated Properties Predictable in Complex Assemblies. J. L. Waisman. (*Iron Age*, 1952, **169**, Feb. 7, 146–149). A method of correlating the hardness obtained with cylindrical test specimens and other shapes is formulated. This system can be used to predict the 'equivalent round' for any cross-section in a part or assembly and hence its mechanical properties after heat-treatment.—A. M. F.

The Accuracy of Measurement in Pre-Load Hardness Testing with a Vickers Pyramid. H. von Weingraber. (*Metallwirtschaft*, 1943, **22**, Mar. 19, 163–165). The accuracy obtained for the hardness by a Vickers pyramid in place of the Rockwell cone is calculated. The errors obtained in the measurement of the depth of the indentation, and of the diagonals, and the measuring accuracy are brought into the calculations, and numerical examples given for various loads and hardness values.—R. J. W.

The Accuracy of Apparatus for Measuring the Impact Hardness of Metals. A. G. Tulinov. (*Zavodskaya Laboratoriya*, 1950, No. 2, 211–216). [In Russian]. Numerous experiments on the determination of impact hardness by the Poldi apparatus, carried out to test the reliability of the method, are described. The main conclusions are: (1) Under suitable conditions, errors can be kept within the range of $\pm$ 7%; (2) large, firmly clamped specimens with carefully cleaned surfaces must be used; (3) the hardness of the standard must be such that the diameters of the indentations do not differ by more than 0·5 mm.; and (4) the impact should be such that the standard indentation diameter is 2·5–4 mm.—S. K.

Hardenability and the Hardenability Testing of Steel. L. Jeníček, J. Koutecký, and F. Labonek. (*Hutnické Listy*, 1951, **6**, May, 220–228). [In Czech]. The determination of hardenability by different methods is discussed. Nomograms are given, and their use for the prediction of hardness of parts of different shape and dimensions is explained with several examples.—P. F.

Absolute Hardness Scale. J. Murkes. (*Tekn. Tidsskr.*, 1952, **82**, Jan. 15, 37–40). [In Swedish]. Methods of hardness determination are critically examined in relation to their ability to fulfil test requirements. An account is given of Krustjov's work towards remedying an important failing in Mohs' scale by establishing a quantitative relationship between the index and actual hardness of standard minerals. The new scale so derived is tabled.—G. G. K.

The Influence of Structure on Hardness with Special Reference to Steels. H. A. Unckel. (Finland Institute of Technology: *Metallurgia*, 1952, **45**, Mar., 115–120). The author discusses the way in which hardness is related to structure in the case of alloys which have particles or grains of a second, harder, phase present in the matrix. Details of experimental results obtained with a number of steels, with special reference to a hypereutectoid plain carbon steel and a high-chromium die steel, are given.—B. G. B.

Sigma-Phase Embrittlement in 25 Cr–20 Ni Heat-Resisting Steels. J. I. Morley and H. W. Kirkby. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 129–142). [This issue].

Discussion on Friction. (Proc. Royal Soc., 1952, Series A, **212**, May 22, 440–520). The following papers were presented

at the Discussion on Friction on April 19, 1951, organized by the Royal Society:

Mechanism of Friction. F. P. Bowden.

Influence of Oxide Films on Metallic Friction. R. Wilson.

Relation between Friction and Hardness. A. J. W. Moore and W. J. McG. Tegart.

Effect of Included Oxide Films on the Structure of the Beilby Layer. A. J. W. Moore and W. J. McG. Tegart.

Formation of Lubricant and Other Films on Clean Metal Surfaces: A Study by Electron Diffraction. R. Courtel.

Surface Changes Due to Sliding. G. I. Finch and R. T. Spurr.

Friction and Cohesion between Single Crystals of Copper. A. T. Gwathmey, H. Leidheiser, and G. P. Smith.

Wear Processes on Cemented Carbide Tools Used in Cutting Steel. E. M. Trent.

Metallic Wear. J. T. Burwell and C. D. Strang.

Comments on the Energetics of the Frictional Process. F. E. Simon.

Comments on the Energy of Deformation during Sliding. A. J. W. Moore.

Comment on the Work Done in Rolling Friction. D. Tabor.

Notes on the Adhesion of Indium in Impact. A. W. Crook.

Comment on the Frictional Behaviour of Porous Metal Impregnated with P.T.F.E. P. P. Love.

Friction of Diamond, Graphite and Carbon. F. P. Bowden, J. E. Young, and G. Rowe.

Frictional Properties of Plastics. K. V. Shooter.

Friction between Single Fibres. N. Gralén.

Some Notes on the Adhesion and Friction of Non-Metals. A. C. Moore.

Mechanism of Boundary Lubrication. D. Tabor.

An Optical Method of Measuring the Thickness of Adsorbed Monolayers. J. S. Courtney-Pratt.

Effect of Surface Structure, Composition, and Texture on Friction under Boundary Conditions. F. T. Barwell.

Mechanism of Action of Extreme Pressure Lubricants. C. G. Williams.

Variation with Load of the Coefficient of Friction and Metallic Transfer under Conditions of Boundary Lubrication. W. Hirst, M. Kerridge, and J. K. Lancaster.

Experimental Study of Sliding Friction. C. A. Maney. (*Amer. J. Phys.*, 1952, 20, Apr., 203–210). This report covers a study on the coefficient of sliding friction at speeds between 0·25–20 cm./sec. For all the materials tested (wood, leather, glass, and various metals including steel) it was found that: (1) The coefficient varies as the logarithm of the speed; and (2) in the case of metal surfaces in contact, the coefficient increases with repeated performance unless the product of the abrasive action is removed for each performance.—E. T. L.

War on Wear. H. Blok. (*Engineering*, 1952, **173**, May 9, 594; May 16, 625–626). The author distinguishes between single-sided wear or erosion by flowing fluids, and double-sided wear characterized by the presence of two solid surfaces rubbing on each other. The effects of temperature and pressure are considered. The phenomenon of pitting, likened to 'surface fatigue,' is examined together with macro-abrasive and micro-abrasive adhesive wear. Methods of reducing wear are considered.—M. D. J. B.

Contribution to Research on Wear Phenomena. R. Mailänder and K. Dies. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, Aug., No. 14, 209–238). A friction pair of a mild-steel specimen with a hardened chromium steel counterpart was used in the investigation on pure sliding friction. Under these experimental conditions the friction was found not to be proportional to the surface pressure, but had marked maximum and minimum values, indicating a transition from one kind of friction to another. Dry friction experiments with rotary motion, and the effect of varying the physical and mechanical conditions such as the velocity, are described. The chemical-physical processes which take place during wear in various atmospheres are discussed. Finally, the knowledge obtained is applied to an investigation of the resistance to wear of different carbon steels in which textures and surfaces were examined metallographically.—R. J. W.

Electric and Metallic Properties of Metals and Alloys. J. A. Bate. (Australian Inst. Metals: *Australasian Eng.*, 1952, Jan. 7, 79–89). The paper is a review of the metallurgical aspects of electrical conductivity, thermo-electricity, and ferromagnetism. The theory of each of these phenomena is discussed, the factors affecting them (such as temperature, alloy additions, cold work, and heat-treatment) are considered, and the practical applications of each are reviewed. (41 references).

Type 416 Retains Magnetic Properties at 450° F. R. H. Esling. (*Iron Age*, 1952, **169**, Mar. 20, 106–108). The magnetic properties of type 416 stainless steel at 450° F. are compared with similar test data taken at room temperature. No significant change was observed in the normal induction properties. A specially designed permeameter of the Fahy type is described.—A. M. F.

Torque Curves and Other Properties of Permanent Magnet Alloys. K. Hoselitz and M. McCaig. (*Proc. Phys. Soc.*, 1952, **65B**, Mar. 1, 229–235). Further investigations of Alcomax III and related alloys have been made using a torque magnetometer. Samples with both columnar and random crystals have been used. Torque curves have been obtained after various sequences of heat-treatment. A method of deriving three independent constants of crystal anisotropy without using single crystals has been devised.—C. J. B. F.

Ferromagnetism and Materials. E. Houdremont. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, Nov., No. 18, 297–312). A discussion of the electron configuration of diamagnetic, paramagnetic, and ferromagnetic atoms leads to a description of the domain theory of magnetism and of the experimental results from I–H measurements on single crystals of ferromagnetics. The advantageous effect of anisotropy in polycrystalline materials is discussed from a crystal orientation viewpoint and also a domain orientation (annealing in a magnetic field). The properties of alloys for permanent magnets and the soft magnetic materials are reviewed.—R. J. W.

Electrical Properties of αFe_2O_3 and αFe_2O_3 Containing Titanium. F. J. Morin. (*Bell Telephone System Tech. Publ., Monograph* 1907; *Phys. Rev.*, 1951, **83**, Sept., 1005–1010). Electrical conductivity, Hall effect, and Seebeck effect were measured on two sets of polycrystalline samples of αFe_2O_3, and αFe_2O_3 containing 0·05–1·0 atomic-% Ti. One set of samples contained 0·6 atomic-% excess of iron and the second set contained 0·6 atomic-% deficiency of iron.—T. E. D.

Laboratory Measurements of Iron Losses at Audio Frequencies. C. C. Horstman and A. Lucic. (*A.S.T.M. Bull.*, 1952, Jan., 64–66). An instrument is described for testing core material for iron core inductor components at frequencies higher than 60 cycles/sec. Details are given of its operation. An accuracy of 2% is maintained below 5000 cycles and comparative tests with similar equipment give results within 0·55–4% at frequencies up to 10,000 cycles/sec.—B. G. B.

Inspection and Electronics. J. R. Cornelius. (*Eng. Insp.*, 1952, **16**, Spring, 15–38). The author discusses at length the nature of electricity and describes how electronic techniques are applied to material segregation, detection of defects in bar stock and components, the sorting of materials, the measurement of stress and strain, and making measurements of length.—P. M. C.

Measuring Wall Thickness. (*Metal Ind.*, 1952, **80**, Apr. 25, 325, 326). A brief description is given of the Dawe ultrasonic thickness gauge which employs dry batteries and is completely portable. The range of the instrument for steel is from $\frac{1}{16}$ to 12 in., and the guaranteed accuracy is $\pm$ 3%.—P. M. C.

Progress in Ultrasonic Flaw Detection—"X-ray" Pictures by Ultrasonics. D. O. Sproule. (*Machinist*, 1952, **96**, Apr. 5, 523–525). By using a persistent screen cathode-ray tube and causing the echoes to brighten the trace instead of deflecting it, an 'ultrasonic image' is produced which can be examined and interpreted like a radiograph. Thus, damped trains of ultrasonic waves can be used for the detection of internal flaws in metals. An ultrasonoscope marketed by Glass Developments Ltd., London, is illustrated.—E. C. S.

The Control of Materials by Ultrasonic Methods. (*Génie Civil*, 1952, **129**, Apr. 15, 154–155). Ultrasonic methods of non-destructive testing are reviewed, and an apparatus called the 'Ultrasonel,' developed by the authors, is described briefly. It enables the extent and exact contours of faults in sheet steel to be detected.—T. E. D.

X-Ray Examination in Practice. T. H. Neijboer and C. H. J. Seijen. (*Lastechn.*, 1952, **18**, May, 50–56). [In Dutch]. The author describes how an X-ray photograph is made. The applications of X-ray examination in welding shops is considered.—R. S.

Examples of Practical Uses of X-Rays in Metallurgy. P. Skulari. (*Hutnické Listy*, 1951, **6**, Oct., 489–494). [In Czech]. The applications of X-ray metallography are illustrated by

examples involving the determination of rolling structures, where the results of the X-ray method were checked by Erichsen tests.—P. F.

The Present Status of Material Testing with X-Rays and Gamma Rays. R. Berthold, O. Vaupel, and N. v. Wetterneck. (*Stahl u. Eisen*, 1952, **72**, Apr. 24, 492–499). The maximum thickness of steel capable of being examined economically by X-ray photography has increased by 15% since the war. This has been achieved through the introduction of improved electrical supply equipment. A marked improvement in photographs with X-rays and γ-rays results from the use of thin lead foils as intensifying screens and of fine-grain film. A graph is presented giving the exposure times for Co60 and Ir192 as a function of steel thickness. The best region for recognizing defects is between 10 and 50 mm. thickness for Ir192 and over 45 mm. for Co60 irradiation; the photographs were quite as good as those taken with X-rays and were in fact superior at greater thicknesses. Some precautions to be taken in the use of radioactive materials are given.—J. P.

31-MeV Radiographic Inspection of Metal Parts. R. Widerŏe. (*Brown-Boveri Rev.*, 1951, 38, Sept.–Oct., 301–310). The great penetrating power of 31 million electron-V. X-rays is very suitable for radiography of thick metal parts. A number of practical examples are illustrated and these show that the fault sensitivity and sharpness of definition of the radiographs obtained are excellent. The radiographic technique is simpler than with the conventional X-ray inspection.—B. G. B.

X-Ray Gage Measures Pipe Wall Thickness. (*Iron Steel Eng.* 1952, **29**, Apr., 126–128). This article describes X-ray operated pipe-wall thickness gauges installed at the Ambridge plant of The National Supply Co. The instruments are high precision, non-contact, continuously indicating electronic micrometers which gauge the thickness and automatically mark under-gauge areas. It is claimed that the instrument can check thicknesses from 0·050 to 1·500 in. with an accuracy of 1%. Brief technical details are given.—M. D. J. B.

A Radiation Research Laboratory. P. P. Starling. (*Engineer*, 1952, **193**, Apr. 18, 533–534). This article describes a new laboratory designed and built by the Metropolitan-Vickers Electrical Co., Ltd. The construction provides safety for those working with X-rays and other forms of radiation at very high intensities. There is an underground portion to accommodate the source of radiation, and rooms above for the control equipment.—M. D. J. B.

Influence of Phosphorus on the Oxidation of Iron at High Temperature. N. Collari. (*Met. Ital.*, 1952, **44**, Mar., 97–102). The mechanism of high-temperature oxidation of phosphorus-bearing iron is examined. Phosphorus can prevent deep oxide formation by the formation of a sub-surface layer rich in iron phosphate.—M. D. J. B.

The Dilatometer and Its Use in Connection with Heat-Resisting Materials. V. Gomez Garcia. (*Inst. Hierro y Acero*, 1952, **5**, Jan., *Special Issue*, 88–92). [In Spanish]. The Chevenard dilatometer and its application to the study of some heat-resisting steels is discussed.—R. S.

Some Current Views on the Mechanism of Creep. L. M. T. Hopkin. (*J. Bham. Met. Soc.*, 1952, **32**, Mar., 15–33). The author first describes the various types of creep curve obtained in practical tests. The salient metallographic characteristics of creep are then reviewed before the various theories suggested by many workers for the mechanism of creep are considered from both the structural and mathematical aspects. (34 references).—P. M. C.

Creep of Metals. (*Automobile Eng.*, 1952, **42**, Apr., 154–156). This article outlines briefly and in an elementary manner the importance of creep data, the methods by which they are obtained experimentally, the method of presentation, and the application of creep data to design problems.—P. M. C.

An Improved Creep Measuring and Recording System. J. W. Huffman. (*Product Eng.*, 1952, **23**, Jan., 172–174). A system for measuring creep, employing linear variable differential transformers and a potentiometer, is described. Two pairs of extensometer arms transfer the elongation to two transformers where the position of a steel slug core gives an out-of-balance voltage dependent on the extension.—A. M. F.

A Constant Stress Creep Test Apparatus. A. Latin. (*J. Sci. Instruments*, 1952, **29**, Mar., 98–99). A creep testing apparatus in which the applied stress is kept constant is described. It is simple in design, has no unbalanced loads, and employs a rocker mechanism in place of movement about a knife edge.—R. A. R.

Trends in Gas Turbine Engine Materials. R. H. Thielemann, J. C. Mertz, and W. P. Eddy, jun. (*S.A.E. J.*, 1952, **60**, Apr., 58–63). The importance of stress-corrosion in addition to creep properties is emphasized, and the results of a series of stress-corrosion tests on ferritic stainless steels are quoted. Compositions and properties are also given for many newly developed high-temperature alloys.—P. M. C.

High Temperature Materials for the Gas Turbine. A. R. Edwards. (Australian Inst. Metals: *Australian Eng.*, 1952, Feb. 7, 64–68). The main requirements for heat-resistant materials in turbine engines are outlined; the rotor presents the chief problems. Creep resistance is shown to be the most important criterion, time-extension curves being the basis of design data. The best of the current alloys are grouped according to their applications and the paper concludes with a short discussion of future trends. (14 references).—P. M. C.

Nickel–Chromium–Molybdenum Steel Valve Casting After 50,000 Hours of Service at 900° F. T. N. Armstrong and R. J. Greene. (*Trans. Amer. Soc.. Mech. Eng.*, 1951, **73**, Aug., 751–754). Extensive tests have indicated that an Ni–Cr–Mo steel conforming to the requirements of A.S.T.M. Specification A-217 is very resistant to graphitization under conditions imposed in the laboratory when testing cast valves and fittings of this composition for steam temperatures up to 950° F.

Experience with Austenitic Steels in High Temperature Service in the Petroleum Industry. M. E. Holmberg. (*Trans. Amer. Soc. Mech. Eng.*, 1951, **73**, Aug., 733–742). Experience in the petroleum industry shows there are other factors beside tensile, creep, and stress rupture to consider in the use of austenitic steels in high-temperature service. There is no advantage in using stabilized grades in many applications. A spheroidizing heat-treatment is generally required. The coefficient of expansion and the thermal conductivity are important factors in thermal-shock and thermal-fatigue failures in austenitic steels.—D. H.

Special Steels for Aircraft Turbines. (*Times Review of Industry*, 1952, **6**, May, 42–45). A survey of research and production in the Sheffield district includes details of the work of the English Steel Corp. and William Jessop and Sons, Ltd. Details are given of creep and fatigue testing of gas-turbine blade alloys, and particular uses of specific alloys are mentioned.—T. E. D.

The Significance to the Engineer of the Science of Materials. W. Köster. (*Z.V.d.I.*, 1952, **94**, Feb. 1, 89–94). The author considers that the science concerned with the properties of constructional materials is a special field, but the designer must have some idea of its elements. These the author briefly expounds, dealing with atomic structure of metals, equilibrium diagrams, effect of microstructure, hardening of alloys, work hardening and recrystallization, and chemical properties.

A High-Strength Die Steel that Can be Cold-Hobbed. G. E. Brumbach. (*Machinery*, 1952, **80**, Feb. 14, 267–272). With the co-operation of the Doehler-Jarvis Corp., Toledo, and the Midland Die and Engraving Co., Chicago, The Carpenter Steel Co., U.S.A., have developed a steel capable of being cold-hobbed, and having high core strength and resistance to abrasion. If sufficient press capacity is available, hobbing no longer need be confined to small dies and relatively shallow cavities.—E. C. S.

Welded Reinforcement of Openings in Structural Steel Members. D. Vasarhelyi and R. A. Hechtman. (*Welding J.*, 1952, **31**, Apr. 169s–183s). The strain-energy distribution and true stresses in plastic range in plates with centrally located openings were determined. Two semi-killed structural steel plates were tested in tension, one at room temperature, the other at − 20° F. The first failed with a shear fracture and the low-temperature specimen with a cleavage fracture. A new method was developed for computing true stresses.

Residual Stress and the Yield Strength of Steel Beams. Progress Report No. 5. Welded Continuous Frames and Their Components. C. H. Yang, L. S. Beedle, and B. G. Johnston. (*Welding J.*, 1952, **31**, Apr., 205s–229s). An analytical and experimental study of the elastic and plastic behaviour of welded continuous steel beams is reported. Stress concentration, residual stresses, and other factors which affect the yield strength of steel members are discussed.—U. E.

Effect of Direction of Rolling, Direction of Straining, and Ageing on the Mechanical Properties of a Mild-Steel Plate. C. F. Tipper. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 143–148). [This issue].

Stress–Strain Relationship of a High-Tensile Weldable

Structural Steel. D. W. Smith, J. G. Whitman, and C. L. M. Cottrell. (*Metallurgia*, 1952, **45**, Apr., 169–172). In the construction of a prefabricated transportable bridge, a manganese steel was replaced by a low-carbon manganese–molybdenum steel. The expected advantages were not realized owing to the lower limit of proportionality between stress and strain exhibited. Several steels were mechanically tested and examined, and the influence of composition was investigated. Improvement could be effected by tempering at 600° C., but prestressing was not beneficial.—B. G. B.

Tests Relating to Deformation in Die Forging and the Relation Between the Strength Properties and the Position of the Specimen in the Part. H. Unckel. (*Metallwirtschaft*, 1943, **22**, Sept. 20, 437–443). Following previous work on the die-forging of aluminium alloys an investigation on deformation is described in which the relation between the strength properties and the position of the specimen in the die-forging was established. Mild steel with 0·1% C and brass with 60% Cu were used. It was shown that the phase structure of the steel specimen affected the strength properties little, but the notched-bar toughness more. In brass the texture was insignificant. The causes are the presence of stringer-like slag inclusions and segregations, whilst with brass, the orientation of the β-phase and lead inclusions are responsible.

The Hard Basic-Bessemer Structural Steels Killed with Silicon and Aluminium. H. Hauttmann. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1941, **9**, Jan., No. 1, 1–15). The possibilities of using a steel with about 48 kg./sq. mm. tensile strength in large structures is first discussed. Owing to the shortage of the old St 48 steel, improvements were made by reducing the carbon content, killing with aluminium and silicon, and increasing the manganese content. Investigations on different rolling methods were carried out on these basic-Bessemer steels by measuring the tensile strength, elastic limit, elongation, and notched-bar strength in the as-rolled state, after ageing, normal annealing, and thermal refining. The alternating tensile, compression, and bending strengths of solid and drilled specimens and the strength properties after electric arc welding were also measured.—R. J. W.

The Quench Ageing of Iron. A. L. Tsou, J. Nutting, and J. W. Menter. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 163–171). [This issue].

Silicon and Aluminium Killed Basic-Bessemer Steel for Ships' Rivets. H. Hauttman. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1941, **9**, Sept., No. 5, 95–104). Experiments with killed and unkilled open-hearth and basic-Bessemer steels are described on rolled rod and finished rivets. Drawing, shearing, cold bending, hot heading, and punching tests were carried out on the rolled rod, together with tensile-impact tests and other bending experiments. The testing of the completed rivets was carried out by hot compression and head-shearing and bending tests. Ships' rivets 16 and 22 mm. in dia. were used to observe the effect of riveting temperature and cold after-drawing on the rate at which the rivet head chipped off.—R. J. W.

Concerning Austenitic Exhaust Valve Materials Low in Scarce Alloying Elements, in Particular the Low Nickel and the Nickel-Free Materials. W. Tofaute and G. Bandel. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, June, No. 12, 193–200). Three comparable austenitic alloys were investigated together with the accepted 15/13/2 Cr–Ni–W-valve steel. The replacing of the customary tungsten by molybdenum, tantalum–niobium, or vanadium, or reducing the tungsten from 2 to 1%, and the effect on the mechanical properties are described. The effect of increasing the chromium content and of exchanging the nickel wholly or partially for an equal amount of manganese, on the ability to nitride and on the mechanical properties and texture is described.—R. J. W.

Fe–Ni–Co Alloys for Glass to Metal Seals. K. H. Mairs. (*J. Met.*, 1952, **4**, May, 460–464). The author discusses the properties and structure of the Fe–Ni–Co alloys 'Kovar' and 'Fernico,' with particular reference to their thermal expansion characteristics and their suitability for glass–metal seals. An important factor in the latter connection is that the alloy should be entirely austenitic and not undergo a crystallographic transformation.—G. F.

Materials—Availability and Trends. (*Product Eng.*, 1952, **23**, Jan., 115–117). The properties of chromium steels which are being used in place of chromium–nickel grades due to the nickel shortage are given in the form of a table. The data include mechanical properties, effect of temperature, working and heat-treating temperatures, and physical properties.—A. M. F.

The Problem of Material in the Further Development of Structural Steel. W. Dick. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1942, **9**, Apr., No. 7, 150–160). The necessity for the rapid and detailed answering of technical development questions on steels is stressed. It is preferable first to carry out a multiple broad series of tests, thus giving a picture of the general applicability. Short examples are given relating to ordinary mild steel. Metallurgical considerations for the brittle and tough behaviour of steels are described together with further technical working details. The treatment gives an insight into the problems that appear in the development of modern structural steels.

Russian and Czechoslovakian Structural Steels. L. Jeníček. (*Hutnické Listy*, 1951, **6**, Nov., 531–537). [In Czech]. The Russian and Czechoslovakian carbon and low-alloy structural steels of all types are reviewed.—P. F.

Elastic Elongation of Chains. L. H. Whitney and P. M. MacDonald. (*Product Eng.*, 1952, **23**, Feb., 176–177). Curves for the elongation against load are given for roller chain, double-pitch conveyor chain, and cable or leaf chains. It is shown that roller chain, having the most elasticity for its strength, is suitable for applications involving shock loads. Double-pitch chain has the least elasticity and should be employed for long conveyors where slack may be troublesome. Cable chain with its high strength and medium elasticity is well adapted to weight lifting or non-rotating applications.

Wire in Prestressed Concrete. (*Wire Production*, 1952, **1**, May, 19). Details are given of relaxation tests on six grades of 0·1-in. dia. wire for prestressed concrete. The tests were of 1000 hr. duration, the specimen length being kept constant by decreasing the stress after 24 hr. of initial constant loading. The stress was found to decrease logarithmically with time, and the differences between the different grades of wire were insignificant when the initial stress was less than 0·03% of the proof stress; the wires with the higher ultimate tensile stress proved superior when the initial stress approached the 0·2% proof stress.—J. G. W.

An Interference Method for the Examination of Rough Surfaces. E. Zehender. (*Z.V.d.I.*, 1952, **94**, May 21, 456–458). A method is described whereby the conventional interference microscope can be used for the examination of surfaces with roughness exceeding 1 μ in depth. A plastic replica of the Fax film type is placed between layers of two different liquids, contained between semi-transparent silvered glass plates. The liquid in contact with the reverse side of the replica should have the same refractive index as the replica so as to render the interference pattern independent of the configuration of the reverse side of the replica.—J. G. W.

Some Notes on Cast Iron. L. Sanderson. (*Eng. Boiler House Rev.*, 1952, **67**, Jan., 16–20; Feb., 54–57). Part I deals with the composition, structure, properties, and testing of cast iron whilst Part II discusses its heat-treatment, working, and uses.—E. C. S.

Notes on Cast Iron—Past and Present. E. Longden. (*Proc. Inst. Brit. Foundrymen*, 1951, **44**, B85–B101). The compositions of special-purpose irons are given. Other topics reviewed include machinability of nodular irons and cupola practice.

Castings to Resist Abrasive Wear. E. J. Brown. (Inst. British Foundrymen: *Foundry Trade J.*, 1952, **92**, June 5, 587–595). Abrasion resistance is a comparative property, and is related to corrosion and hardness. The author describes how manganese steel and alloy cast irons have been developed to give improved service. Flame-hardening, nitriding, and deposition of abrasion-resistant coatings are also considered.

Ductile Cast Iron. M. M. Hallett. (*Trans. Inst. Marine Engrs.*, 1952, Feb., 25; *Steam Engineer*, 1952, **21**, May, 309–312). The properties of ductile cast iron produced by the magnesium process are summarized. The change in the microstructure from graphite flakes to graphite spheroids, which can be combined with any form of metallic matrix, each conferring its characteristic properties, is described. In the 'as cast' state, tensile strength varies from 35 to 45 tons/sq. in. and for the annealed material from 29 to 34 tons/sq. in., with elongation ranging from 10 to 20%. Details of magnetic and electrical properties, and heat, corrosion, and wear resistance are given.—T. E. D.

The Properties and Specifications for Castings of Modified Cast Iron. S. Pelczarski. (*Przeglad Odlewnictwa*, 1952, **2**,

4, 111–120). [In Polish]. The strength of separately cast specimens and those cut from different places in one casting with varying wall thickness were compared. Some properties of modified cast iron, such as a diminished tendency to cementite crystallization and resistance to abrasion, are outlined, and the possibilities of improving the mechanical properties by suitable heat-treatment discussed.—V. G.

Scientific and Technical Conference for the Extension of the Use of Modified Cast Iron in Polish Industry. Krakow, 13–15, Feb. 1952. (*Przeglad Odlewnictwa*, 1952, **2**, 4, 121–123). [In Polish]. The proceedings of the conference are briefly reported. The conference was called to improve the co-ordination of work between designers and foundry engineers in the uses of modified cast iron, and to stimulate research on its properties.—V. G.

Medium Chromium Cast Irons. (*Fonderie*, 1952, Jan., 2784–2786). The two main fields of application of medium chromium cast irons are: (1) Parts for resisting temperatures up to 700° C.; and (2) parts for resisting acid attack. The relationship between silicon and chromium contents is considered. Precautions necessary against increased brittleness and low hot impact strength are stated.—R. S.

Statistical Study of the Correlation between the Composition of Ordinary Cast Iron and Its Mechanical Properties. J. Drachmann. (*Fonderie*, 1952, Jan., 2755–2762). Depth of hardening, machining tests, hardness, and the carbon, silicon, manganese, and sulphur contents were noted in a series of tests over 15 months. Statistical methods were applied to study the relationships.—R. S.

Uses of Tungsten. C. More. (*Mét. Constr. Méc.*, 1952, **84**, Jan., 25–29; Mar., 159–162). The author describes some iron–tungsten alloys and tungsten steels and discusses the uses of tungsten carbide tools.—R. S.

Research Laboratories of Babcock and Wilcox Ltd. (*Engineer*, 1952, **193**, June 27, 857; July 4, 10–11). **Engineering and Metallurgical Research by Babcock & Wilcox, Limited, at Renfrew.** (*Engineering*, 1952, **173**, June 27, 797–801). **New Research Station of Babcock & Wilcox Ltd.** (*Iron Coal Trades Rev.*, 1952, **164**, June 27, 1413–1418). **Research by Babcock and Wilcox Ltd.** (*Colliery Guardian*, 1952, **185**, July 3, 25–29). **Fuel Studies at the Renfrew Research Station of Babcock and Wilcox Ltd.** (*J. Inst. Fuel*, 1952, **25**, July, 159). **Research and Development at Renfrew.** (*Eng. Boiler House Rev.*, 1952, **67**, July, 190–196). **The B. & W. Research Station.** (*Steam Engineer*, 1952, **21**, July, 380–384).

METALLOGRAPHY

New Techniques of Metallurgical Research. (Institute of Metals: *Metal Treatment and Drop Forg.*, 1952, **19**, Apr., 166–170). Recent innovations and aids to microscopy and physical testing of metals were discussed at a recent meeting of the Birmingham section of the Institute of Metals. This article records the observations of several speakers on the following topics: Diamond dust for metallographic polishing; high-temperature microscopy; geiger counters; powder metallurgy; the measurement of surface topography; load-strain recorders; and specification creep testing.—P. M. C.

New Precision Cameras for Studying Microstructure by X-Rays. G. Freyer and T. Lohmann. (*Technik*, 1952, **7**, Mar., 122–124). The development of a Debye-Scherrer, rotating crystal, and universal plane cameras, is described, constructional details are given, and the performance of each camera is illustrated by examples.—J. G. W.

Electron-Microscope Surface Replicas of Some Metallic Materials by the Resin Replica Process. Edith Semmler-Alter. (*Metallwirtschaft*, 1943, **22**, June 20, 303–307). With the help of acid solutions, the attached resin layer for the electron microscope surface investigations of different metallic materials can be isolated. The composition and mode of manipulation of the baths is described. The removal of the replica film is described for carbon steel, austenitic Cr–Ni steel, and several non-ferrous metals and alloys. The electron micrographs are compared with high magnification optical micrographs.

R. J. W.

A Technique for Making Strain-Free Replicas for Electron Metallography. W. L. Grube and S. R. Rouze. (*A.S.T.M. Bull.*, 1952, Jan., 71–73). Polyvinyl formal plastic replicas show strain marks when removed from the specimen by 'dry stripping.' A technique is described in which another plastic, soluble in a solvent in which polyvinyl formal is insoluble, is used to back the replica. The backed replicas are then more easily handled and removed. An account is given of the complete operation of making replicas which can be successfully used on nearly all metal specimens.—B. G. B.

High-Voltage Apparatus for Electron Micrography. I. I. Yamzin. (*Zavodskaya Laboratoriya*, 1950, No. 2, 178–181). [In Russian]. A description, with circuit diagrams, is given of the construction and performance of an apparatus for providing stable voltages of the order of 50 kV. for prolonged periods. The apparatus is very simply constructed and may be used with the electron microscope and for X-ray work.

S. K.

Dispersion-Analysis of Spherical Particles in an Opaque Medium. A. G. Spektor. (*Zavodskaya Laboratoriya*, 1950, No. 2, 173–177). [In Russian]. A simplified method is described of determining the size distribution of approximately spherical particles in an opaque medium by the microscopical examination of polished sections. The method is based on the distribution of chords obtained from the intersection of the circular particle sections with a straight line on the polished section or its image. The method is exemplified by application to carbide particles in annealed hypereutectic steel and ferrite particles in normalized low-carbon steel.—S. K.

Grain Size of High-Alloy Austenite as a Factor in Its High-Temperature Strength. A. M. Borzdyka. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Khimicheskikh Nauk*, 1949, No. 2, 121–127). The influence of grain size on the creep strength of alloyed austenite in the absence of precipitation hardening was investigated. The relative influence of the precipitation process and the grain size and the effect of the presence of spheroidal carbide were also studied.—V. G.

Rapid Method for Investigating the Structure of Large Ingots by Explosive Charge. M. Signora and G. Testero. (*Met. Ital.*, 1952, **44**, May, 180–183). The authors describe a method of investigating metal fracture along the longitudinal axis of medium and large steel ingots. An account is given of tests carried out with explosives. The results obtained are reliable, rapidly arrived at, and give a clear idea of the primary structure and compactness of the ingots as well as showing up internal defects.—M. D. J. B.

Solubility of Carbon in 18-Percent-Chromium 10-Percent-Nickel Austenite. S. J. Rosenberg and C. R. Irish. (*J. Res. Nat. Bur. Stand.*, 1952, **48**, Jan., 40–48). A series of high-purity Fe–Cr–Ni alloys, made to a base analysis of 18% Cr and 10% Ni, and with carbon ranging from 0·007 to 0·30%, was melted and solidified *in vacuo*. The presence or absence of carbides in these alloys after various mechanical and thermal treatments was determined by metallographic examination. The practical limits of solubility varied from less than 0·007% C at 1300° F. to slightly more than 0·077% at 1975° F. The presence of ferrite and/or sigma as stable phases in many of the alloys was established.—C. J. B. F.

Recrystallization Kinetics of Alloyed Iron. L. I. Kogan and R. I. Entin. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20**, 5, 629–632). An investigation of the kinetics of recrystallization of Armco iron alloyed with chromium, nickel, tungsten, molybdenum, cobalt, silicon, and manganese is reported. An X-ray technique was used. The activation energies of the recrystallization process were calculated for the individual alloys.—V. G.

Measurement of Cooling Speeds by Cathode-Ray Oscillograph. E. B. Simonsen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1952, **12**, Feb., 36–39). [In Norwegian]. Results are given of tests, made in connection with the formation of grain-boundary cementite, in which cooling rates of test samples, quenched in water and molten lead, were satisfactorily measured and recorded by a thermocouple and cathode-ray oscillograph. Method and apparatus are described and test oscillograms are shown.—G. G. K.

The Domain Structure of a Silicon–Iron Crystal. L. F. Bates and C. D. Mee. (*Proc. Phys. Soc.*, 1952, **65A**, Feb. 1, 129–140). Powder patterns have been obtained on the (100) and (011) surfaces of a carefully shaped single crystal of 3% silicon–iron, measuring 13 × 6 × 6 mm., and these have permitted a more thorough quantitative test of proposed ferromagnetic domain structures than has been made hitherto. The patterns on the (011) surface are very beautiful and complicated. Although the measurements of domain spacings on both planes under Mode III magnetization conditions, as well as measurements of the angles between the domain vectors and main domain boundaries, confirm the essential features of the main structure proposed by Néel, there are discrepancies.—C. J. B. F.

Soft X-Ray L-Spectra of Fe, Co, Ni, Cu and Their Oxides. K. Das Gupta and S. B. Bhattacherjee. (*Indian J. Phys.*, 1951, **25**, Nov., 555–559). The L_2, L_3 bands of Fe–Cu and their oxides have been investigated in the region 13–18 Å. with bent mica and gypsum crystal in Siegbahn's vacuum grating spectrograph. L_3 bands of Fe–Ni have more or less the same energy width of 13–16 electron-volts. In these elements a weak extended structure on the short wavelength side of the main L_a band has been observed.—B. G. B.

Chromium Carbide in Stainless Steel. A. B. Kinzel. (Trans. Amer. Inst. Min. Met. Eng.: *J. Met.*, 1952, **4**, May, 469–488). The author discusses precipitation phenomena and the mechanism of carbide formation in 18/8 stainless steels. It is shown that, when the carbon content is greater than the limit of solid solubility, the carbide $Cr_{23}C_6$ is precipitated. The carbide is essentially two-dimensional in character, its shape being determined by the degree of registry of atomic planes intercepting the interface.—G. F.

Formation of Grain-Boundary Cementite in Low-Carbon Steels. E. B. Simonsen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1952, **12**, Mar., 51–56). [In Norwegian]. Rickett and Kristufek have established that maximum deposition of cementite from pearlite was at 425° C. and that cementite could be deposited direct from ferrite at very high cooling rates. Görrissen, however, differentiates between two types of cementite: Grain-boundary, when the solubility of carbon is exceeded during cooling, and that caused by a slow diffusion process, the maximum rate being at 675 and 690° C. The apparent disagreement between these theories was examined. Results presented tend to show that austenite during transformation can deposit cementite in a form closely resembling the grain-boundary cementite.—G. G. K.

Isothermal Mode of the Martensitic Transformation. E. S. Machlin and M. Cohen. (Trans. Amer. Inst. Min. Met. Eng.: *J. Met.*, 1952, **4**, May, 489–500). The authors have examined theoretically and experimentally the isothermal formation of martensite in a 71/29 Fe–Ni alloy. The formation is found to take place mainly by nucleation of new plates rather than by growth of existing ones, and is dependent on temperature and time, the amount of athermal martensite present, the state of internal strain, and the application of tensile stress. The conclusion is reached that isothermal nucleation is activated by thermal fluctuations superimposed on localized regions of very high strain.—G. F.

The Influence of Quenching Temperature on the Amount of Residual Austenite in Steel. V. D. Sadovskii and G. N. Bogacheva. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **83**, 2, 221–222). [In Russian]. Experimental evidence indicates that the relation between the amount of residual austenite and the quenching temperature of steel suggested by W. J. Harris, jun., and M. Cohen (*see J. Iron Steel Inst.*, 1949, **161**, Feb., 166) is incorrect, since they did not consider the strongly graphitizing influence of nickel.—V. G.

Application of the Dilatometric Method to the Investigation of the Martensite Transformation in the Negative Temperature Range. I. L. Mirkin and V. S. Egorov. (*Zavodskaya Laboratoriya*, 1950, No. 2, 161–168). [In Russian]. A dilatometric technique for studying phase transformations in steel at temperatures down to − 196° C. is described. After a detailed description of the apparatus, dilatometric curves obtained for specimens of KhNVA alloy steel under various conditions are presented and discussed. It is claimed that the method makes it possible to establish: (1) The starting point and the deceleration range of the martensite transformation; (2) the kinetics of this transformation at sub-zero temperature and its course under isothermal conditions; and (3) the possibility of suppressing the martensite transformation at low temperatures and restarting it by reheating.—S. K.

Contribution to the Metal–Carbon–Boron Systems. F. W. Glaser. (Trans. Amer. Inst. Min. Met. Eng.: *J. Met.*, 1952, **4**, Apr., 391–396). From an X-ray diffraction study of hot-pressed metal–carbon–boron powder mixtures, it is found that, regardless of the initial composition of the powder, a metal-boride phase is always the major component of the pressed sample. In the absence of carbon, this boride phase depends only on the amount of boron present. In the titanium–boron system, two new phases, Ti_2B and Ti_2B_5, have been found, whilst the existence of the controversial face-centred cubic phase TiB has been confirmed. The diborides are generally better conductors than the monoborides of the same metal.—G. F.

The Influence of Cobalt upon Diffusion of Carbon in Austenite. M. E. Blanter. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20**, 8, 1001–1004). The influence of cobalt on the diffusion coefficient of carbon in austenite was investigated between 1000 and 1200° C. and for cobalt contents up to 21%. Equations expressing the temperature dependence of the diffusion coefficient with different cobalt contents are given.—V. G.

Equilibrium Conditions with Iron–Chromium–Carbon Alloys. I. L. Mirkin and M. E. Blanter. (*Metallurg*, 1940, **15**, 8, 3–8). Carbide phases in the iron corner of the Fe–Cr–C system were investigated by X-rays, resistance measurements, and magnetic methods. On the basis of experimental results, the isothermic cross-section (at 20° C.) of the Fe–Cr–C diagram was plotted and, when compared with Tofaute's diagram, showed that the boundaries of the phase areas were consistently shifted with respect to chromium concentration.

Use of Isoactive Lines in Ternary Constitution Diagrams. M. Hillert. (*Jernkontorets Ann.*, 1952, **136**, Feb., 25–37). [In Swedish]. A general property of isoactive lines was derived and demonstrated in five applications. Results given include: The ' para ' state two-phase region is smaller than the ' ortho ' state; the direction of up-hill diffusion of carbon in some alloy steels was determined from the phase diagrams; an earlier explanation of the non-formation of a surface zone containing carbide was not confirmed.—G. G. K.

CORROSION

Metallic Corrosion. W. H. J. Vernon. (*Research*, 1952, **5**, Feb., 54–61). The principles of metallic corrosion are broadly surveyed, with especial reference to the controlling factors in immersed, underground, and atmospheric corrosion, and their application to the prevention of corrosion under service conditions.—C. J. B. F.

Micro-Organisms and the Corrosion of Metals. G. Banfi. (*Chim. e Indust.*, 1952, **34**, Jan., 17–21). [In Italian]. Consideration is given to the effects of iron, manganese, and sulphur on soils and a parallel is drawn between the organic action of these elements and the action of micro-organisms on metal corrosion. The experimental technique adopted in these studies is discussed, and the results of this action in certain particular cases described.—M. D. J. B.

Further Research on " Evans " Cells. K. Wickert and H. Wiehr. (*Werkstoffe u. Korrosion*, 1952, **3**, Apr., 129–142). The authors studied the behaviour of the differential aeration (" Evans ") corrosion cell, paying particular attention to making the total resistance of the circuit, cell plus external resistance, as low as possible. With a special diaphragm, they succeeded in constructing cells with a resistance as low as 10 ohms, which is considerably less than any value previously reported in the literature. The behaviour of these cells was markedly affected by the surface preparation of the electrodes. Thus, with filed iron electrodes the cathode (exposed to oxygen) suffered an appreciable loss in weight at low current densities and this loss only became greater than that of the anode (exposed to nitrogen) when the current density rose above 0·14 m.amp./sq. cm. With polished iron electrodes, however, no loss in weight occurred at the cathode at any current density. By using a flowing electrolyte instead of a stagnant one, the *p*H of the electrolyte was maintained at constant values in either or both cell compartments. Variations in the *p*H had a profound influence on the results. For example, a reversal of polarity was observed when the nitrogen electrode was immersed in a solution of *p*H 13 and the oxygen electrode in a solution of *p*H 6·5; the nitrogen electrode became the cathode. Other tests were made in which single elements of the Evans cell were coupled with other standard half cells. The authors attribute the phenomena observed by them to the effects of the various physical and chemical factors on the films present on the electrode surfaces.

Chemical Treatment to Mitigate Corrosion. J. G. Jewell. (*Corrosion*, 1952, **8**, Mar., 100–108). The author reviews surface active and ionic types of corrosion inhibitor, methods of neutralization and buffering, removal of corrosive agents, self-repairing coatings, and bactericides. Anodic and cathodic agents are considered at length and the factors affecting the use of these types of inhibitor are described. Industrial applications of anodic and cathodic agents are described. Organic inhibitors, absorption inhibitors, pickling inhibitors, oil-wetting agents, and special applications of anti-corrosion additions are considered.—G. P. A.

Corrosion—Its Causes and Prevention. A. Marsden. (Inst. Gas Engineers: *Indust. Finishing*, 1952, **4**, Feb., 515–526; Mar., 612–616; Apr., 697–699). **Preventive Measures Against Corrosion.** A. Marsden. (*Gas World*, 1952, **135**, Mar. 29, 314–317). The nature and mechanism of corrosion, particularly of ferrous materials, the factors which aggravate or determine its rate, and methods of prevention are discussed.

The Interaction of Iron and Ozone. R. Kh. Burshtein and N. A. Shumilova. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **83**, 2, 251–252). [In Russian]. The oxidizing effects of ozone and oxygen on spectroscopically pure iron were compared. It was found that at 190° K., the oxide layer formed by ozone was somewhat thicker than that formed by oxygen. At 290–430° K. the thickness of the oxide layer formed by both gases was identical.—V. G.

Structure and Corrosion. G. V. Akimov. (*Izvestia Akademii Nauk S.S.S.R. Otdelenie Khimicheskikh Nauk*, 1951, No. 5, 469–480). [In Russian]. A general review of corrosion phenomena such as types of destruction, and the velocity of corrosion in oxidizing and non-oxidizing media, is presented.

Irreversible Electrode Potentials of Iron in Electrolytes Containing Corrosion Inhibitors. I. L. Rozenfel'd. (*Izvestiya Akademii Nauk S.S.S.R. Otdelenie Khimicheskikh Nauk*, 1951, No. 6, 674–677). [In Russian]. The relationship between protective properties of corrosion inhibitors (sodium nitrite and zinc sulphate), the mechanism of their action, and electrode potential was investigated. Depending on the mechanism of the action of the inhibitors, the irreversible electrode potential of iron varies.—V. G.

Intercrystalline Corrosion of Alloys. G. V. Akimov. (*Izvestia Akademii Nauk S.S.S.R. Otdelenie Khimicheskikh Nauk*, 1951, No. 1, 13–25). [In Russian]. The classification of the main types of corrosive destruction with particular reference to intercrystalline corrosion is discussed. Intercrystalline corrosion of alloys must be considered on the basis of the theory of multi-electrode systems. The micro-electrochemical method, on the basis of the multi-electrode system, allows the construction of polarization diagrams. Protective measures against intercrystalline corrosion are described.

Passivity of Iron–Nickel–Chromium Alloys in Alkaline Solutions. L. M. Volchkova, L. G. Antonova, and A. I. Krasilshchikov. (*Zhurnal Prikladnoi Khimii*, 1951, **25**, 12, 1445–1449). [In Russian]. The behaviour of anodes made from iron–nickel–chromium alloys in 0·1*N* and 5*N* solutions of sodium hydroxide at 80° C. was investigated. Chromium, which causes passivity of stainless steels in acid media, considerably diminishes their resistance in alkaline media. The passivity of nickel in alkaline media is also conveyed to its alloys with iron. Alloys containing 25% and 46% of nickel were as resistant to alkali as nickel itself.—V. G.

Stress-Corrosion Cracking of Mild Steels in Nitrate Solution. R. N. Parkins. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 149–162). [This issue].

Film-Rupture Mechanism of Stress Corrosion. H. L. Logan. (*J. Res. Nat. Bur. Stand.*, 1952, **48**, Feb., 99–105). The atmospherically formed protective films were removed by abrasion in an argon atmosphere from surfaces of an aluminium alloy, two brasses, a magnesium alloy, and low-carbon and stainless steels. The resulting surfaces were 0·12 to 0·76 V. more negative with respect to a calomel electrode than surfaces prepared and measured under normal atmospheric conditions. Appreciable changes in electrochemical solution potentials of notched specimens, stressed in tension, occurred at or just above stresses at which the true-stress/true-strain curves deviated from the modulus lines. These changes in potential were caused by rupturing of the protective films at the roots of the notches and were of the order of 0·16 to 0·70 V. at failure, depending on the material. Stress corrosion is postulated to occur in corrosive media, at stresses sufficient to rupture the protective film, by electrolytic action between the filmed (cathodic) and the film-free (anodic) areas.—C. J. B. F.

Prevention of Corrosion of Ships in Sea Water by Means of Cathodic Protection. K. N. Barnard. (*Research*, 1952, **5**, Mar., 117–125; Apr., 176–180). The experience of the Naval Research Establishment, Halifax, Nova Scotia, with cathodic protection as a means of preventing the corrosion of ships in sea water is described, and the economic aspects of the use of such a system are discussed. The first part deals with the use of magnesium anodes as a means of protection and the second part concerns impressed current systems.—C. J. B. F.

Prevention of Corrosion by Metallic Coatings. U. R. Evans. (*Research*, 1952, **5**, May, 220–225). An outline is given of the electrochemical principles underlying the method of protecting steel from corrosion by means of metallic coatings. Examples are given of anodic and cathodic coatings, and methods of application are discussed.—C. J. B. F.

Hydrogen Evolution from the Tin–Iron Couple in Alkaline Solution. S. C. Britton. (*J. Appl. Chem.*, 1951, **1**, Suppl. Issue 2, s132–s136). The corrosion of tin in strongly alkaline solutions may be accelerated by contact with iron and may proceed even when oxygen is absent, hydrogen being evolved from the iron. The degree of acceleration depends on the area of exposed iron. The area exposed at pores in tinplate is likely to have only a very small effect, but in packing alkaline materials in tinplate containers, the use of black-plate ends on the container or the inclusion of metallic iron in the product introduces a risk of a rise in pressure owing to hydrogen evolution.—E. C. S.

Tests Relating to the Corrosion of Bolts for Steam Pipelines. K. Dies. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, Apr., No. 9, 111–126). The 'binding' of ¾-in. bolts (to DIN 240) after 500 hr. annealing at 500° C. in air was investigated. A large difference between the tensile strengths of the nut and the bolt increased the binding. The effect of increasing the stresses, of the form of the thread and of the material of the nut and bolt was investigated. Lubrication, and coating the threads with a metallic coating (*e.g.*, chromium) and with non-metallic coatings such as phosphatizing, oxidizing, or nitriding, are described together with their effect on the corrosion, and hence on the efficiency of the nut and bolt.—R. J. W.

Fretting as a Chemical-Mechanical Process. K. Dies. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1942, **5**, Apr., No. 10, 127–140). Wear experiments on numerous friction pairs indicated that the appearance of frictional oxidation is not always immediately dependent upon their hardness, but chiefly depends upon the hardness and adhesion properties of the products of friction. X-ray and analytical methods indicated the formation of very hard corundum by the rubbing of aluminium. This hard material would then attack the parent substance. A high attacking ability was also shown by austenitic stainless steel. Copper and zinc show a favourable behaviour. In the absence of oxygen, no oxidation could take place.—R. J. W.

Damage to the Blades of Turbo Gas Exhausters. E. Thomann. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1943, **10**, Apr., No. 2, 25–29). Damage to blades and blade rivets of exhausters for coke-oven batteries is discussed. Three kinds of damage are noted: That due to (*a*) running at excessive speed; (*b*) visible corrosion; and (*c*) invisible corrosion.—R. A. R.

Improved Apparatus for Corrosion Testing. V. V. Glushenko. (*Zavodskaya Laboratoriya*, 1950, No. 2, 236–238). [In Russian]. An improved apparatus for corrosion testing in a stream of liquid is described. Three cylindrical specimens are dealt with simultaneously, a mixture of liquid and air being circulated through the 1-mm. annulus between the specimen and the glass tube containing it. The compactness of the apparatus facilitates temperature control and the visual and photographic observation of local corrosion. Results obtained for local corrosion of steel at 40, 60, 80, and 90° C. in steam condensate, and corrosion isotherms for steel in alkaline solutions of chlorides at 60° C. are presented and discussed.

An Investigation of the Corrosive Effects of Soils on Steel Plates. G. D. Gemmell. (*New Zealand J. Sci. Techno.*, 1952, **33**, Jan., 287–298). Plates of mild steel, buried in different parts of New Zealand in 1934 were taken up in 1946–47, cleaned and weighed, and the pit depths measured. No simple relationship was found between any one soil characteristic and corrosiveness, but high corrosiveness of a soil can often be detected by an extreme value for one or more of its properties. The extent of corrosion was predictable from laboratory tests and knowledge of field conditions in 75% of the tests, but did not conform with the evidence in the other 25%.—B. G. B.

Condensed Phosphates and Corrosion Control. B. Raistrick. (*Chem. Indust.*, 1952, May 10, 408–414). The use of small concentrations of condensed chain phosphates for the control of corrosion by natural waters has been studied and compared with the use of similar concentrations for inhibiting the deposition of calcite from supersaturated calcium carbonate solutions, the mechanism of which has been revealed by X-ray

examination. An important factor is the ability of these condensed phosphates to become adsorbed on one particular face of the calcite structure, since this face is found in the correct orientation when calcite is deposited on a steel surface. Theoretical views that this control is cathodic have been confirmed. The essential mechanism appears to be the deposition of a compound in which the cations are in layers, such compounds being very resistant to erosion and giving adequate protection.—J. O. L.

The Use of Radioactive Tracers in the Study of the Mechanism of Action of Corrosion Inhibitors. D. M. Brasher and E. R. Stove. (*Chem. Indust.*, 1952, Feb. 23, 171–172). Radioactive chromium (Cr^{51}) and carboxyl-carbon (C^{14}) have been used to determine the amount of corrosion inhibitor remaining on the surface of mild steel after immersion respectively in potassium chromate or sodium benzoate solution, and subsequent washing. The inhibitor is adsorbed in the surface film and its quantity is largely dependent on the concentration of the solution and time of immersion. After three days in solution, about 1 μg. of Cr_2O_3 per sq. cm. was found in the former case and about 0·07 μg. of sodium benzoate in the latter.—J. O. L.

Inhibitors and Promoters of Corrosion in Liquid Media. L. Cavallaro and A. Indelli. (*Rev. Mét.*, 1952, **49,** Feb., 117–124). The action of chromates and nitrites in neutral and acid media, on ordinary and stainless steels has been studied. The two inhibitors differ markedly in neutral media. In addition, the action of chromates on couples of Fe–Monel/Fe–Ni and ordinary-steel/stainless-steel, and the promoting effect of anhydrous sulphuric acid are investigated.—A. G.

A Critical Look at Salt Spray Tests. F. L. LaQue. (*Mat. Methods*, 1952, **35,** Feb., 77–81). Although widely accepted as a means of measuring the resistance of materials and finishes to corrosive environment, salt-spray tests are still highly controversial and are considered unreliable and misleading by many engineers. The author here presents the case, supported by experimental evidence, against the test.

Alternate Immersion Corrosion Test Equipment. Chuk-Ching Ma. (*Indust. Eng. Chem.*, 1952, **44,** Mar., 583–585). An improved design of alternating immersion corrosion test equipment is described. The three main features of this new design are: (1) The test samples are hung in a position that will ensure equal duration of immersion of all parts of the samples in the corrosive media; (2) the samples are moved continuously up and down, so as to distribute the corrosive conditions uniformly over the specimens; and (3) the equipment is structurally simple and convenient to use.—C. J. B. F.

Cathodic Protection of Moving Underwater Equipment. W. S. Merrithew. (*Corrosion*, 1952, **8,** Mar., 90–92). Application of cathodic protection to moving underwater equipment in California has proved successful. Since 1944 protection with a coating of coal-tar enamel has been augmented by cathodic protection using iron-pipe anodes and an applied current. In the flocculators, the anodes are installed on wall brackets, but in the clarifiers, they rotate with the equipment. Drag-chain scrapers in a clarifier installation made in 1949 were provided with cathodic protection using magnesium anodes. Examination after one year indicated adequate protection.—G. P. A.

Some Effects of Cathodic Protection on Conventional Paints. L. P. Sudrabin, F. J. LeFebvre, D. L. Hawke, and A. J. Eickhoff. (*Corrosion*, 1952, **8,** Mar., 109–114). The use of cathodic protection on painted steel immersed in water has been investigated. In fresh water, blistering of paint increased rapidly with increasing potential across the paint film. Although considerable blistering was observed when the potential against a calomel half cell did not exceed 850 millivolts, the paint films materially assisted cathodic protection. In sea water, increased potential also resulted in increased blistering, but below − 1000 mV., blistering after 1½ years was not appreciably more than occurred on specimens not cathodically protected.—G. P. A.

The Chemistry of Marine Corrosion. C. H. Blair. (*J. Amer. Soc. Naval Eng.*, 1952, **64,** Feb., 121–126). The theory of the corrosion of metals is discussed with particular reference to ships' hulls. Combination of dissimilar metals in electrical contact should be avoided wherever possible, and zinc protectors used where such couples exist.—G. P. A.

Cavitation Mechanics in the Design of Hydraulic Equipment. R. T. Knapp. (*Engineer*, 1952, **193,** Apr. 25, 571–574: *Engineering*, 1952, **173,** Apr. 25, 533–536: *Inst. Mech. Eng. Preprint*, Apr. 18, 1952). The author outlines the characteristics of the cavitation phenomenon and points out how this knowledge may be used to alleviate and, in some cases, to eliminate the losses due to cavitation. It is shown that there is difficulty when cavitation is encountered over the entire field of hydrodynamics, but that, although the manifestations may appear to differ widely, they can usually be understood on the basis of present concepts of the mechanics of cavitation.

Scale in Turbine Blading: Its Cause, its Influence on Performance and its Prevention. R. T. Rolfe. (*Iron Steel*, 1952, **25,** Feb., 53–55). The author discusses the circumstances in which scale formation on turbine blades may occur, and describes the detrimental effect on the turbine performance. Methods of preventing the deposition of the salts and of removing them from the blades are considered.—G. F.

Protection of Steel Against Atmospheric Corrosion: Contribution by Belgian and British Scientists. (*Iron Coal Trades Rev.*, 1952, **164,** Apr. 4, 757–760, 766). A report is given of a joint meeting of the Corrosion Group of the Society of Chemical Industry and the Association Belge pour L'Etude, L'Essai, et L'Emploi des Materiaux, held in March, 1952, when Belgian and British work on the study of corrosion was reviewed with special reference to the protection of steel under various atmospheric conditions. The effects of impurities, and the surface preparation of steel in open-air exposure tests and in marine atmospheres, are among the factors discussed.—G. F.

Atmospheric Exposure Tests on Nailed Sheet Metal Building Materials. T. H. Orem. (*U.S. Dept. Commerce, Nat. Bur. Standards, Buildings and Structure Report* 128, 1952, Mar. 28, 1–24). Tests on nailed building sheets of aluminium, aluminium alloy, aluminium-coated steel, galvanized steel, and zinc alloy exposed for two years are described. Some good sealing washers, nails, and wood coatings in each instance are proposed.—T. E. D.

ANALYSIS

The Use of Polarography in the Analysis of Metals. K. Schmidt. (*Hutnik* (Katowice), 1952, **19,** Mar., 90–95). [In Polish]. The principles and applications of polarography are surveyed. A list of half-wave potentials of the most common inorganic ions in several electrolytes are given.—V. G.

Electronically Controlled AC Interrupted Arc Source for Spectrographic Purposes. A. Bardocz. (*J. Opt. Amer.*, 1952, **42,** May, 357–359).

Spectroscopy of Steel. W. Klimecki. (*Hutnik* (Katowice), 1952, **19,** Mar., 86–90). [In Polish]. A general description of the apparatus and methods used in the spectroscopic analysis of steel is given.—V. G.

Determination of Silicon in Steel by Titration. J. Korecký and B. Kysil. (*Hutnické Listy*, 1951, **6,** Nov., 541–544). [In Czech]. Methods of determining silicon in steel, with special reference to Štolba's work involving the precipitation of the silica as potassium fluoro-silicate, after having dissolved the hydrated colloidal silica in hydrofluoric acid, are reviewed. Details are given of the methods used at the Poldi works.

The Determination of Columbium in Tungsten-Free High Alloys. R. B. Golubtsova. (*Zhurnal Analiticheskoi Khimii*, 1951, **6,** 1, 34–38). A method of determining niobium in tungsten-free high-alloy steels is proposed. It is based on the separation of niobic acid with silica in the usual manner. After the removal of silica, the niobic acid is dissolved in water and reprecipitated by hydrolysis with 2% HCl.—V. G.

Photometric Determination of Tungsten and Silicon in Steel. S. Gregorczyk. (*Hutnik* (Katowice), 1952, **19,** Mar., 80–85). [In Polish]. A description of the analytical procedure for the photometric determination of tungsten and silicon in steel is given.—V. G.

Spectroscopic Determination of Phosphorus in Steel. E. S. Kudelya and A. S. Dem'yanchuk. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **83,** 3, 397–398). [In Russian]. The spectroscopic determination of phosphorus in steel using line P.II.6043·05 Å. is proposed.—V. G.

Metallurgical Micro-Analysis. E. C. Pigott. (*Metal Treatment and Drop Forg.*, 1952, **19,** Apr., 147–154). The author describes the various forms of micro-analysis, their potentialities, and the development of techniques and apparatus in recent years. The latest types of micro-chemical balance and spectrophotometer are discussed, and the special apparatus needed in a microchemical laboratory is detailed. (14 references).—P. M. C.

A New Colorimetric Reagent for Molybdenum. J. H. Yoe and F. Will. (*Anal. Chim. Acta*, 1952, **6**, May, 450–451). 'Tiron' gives a bright yellow colour with molybdenum (VI). Measurements with a Beckman Model DU Spectrophotometer with a 1-cm. cell allow the determination of one part in 10^7 parts of solution under optimum conditions (wavelength 390 mμ, *p*H 6·6–7·5).—T. E. D.

The Determination of Copper in Steel by Internal Electrolysis. D. L. Carpenter and A. D. Hopkins. (*Analyst*, 1952, **77**, Feb., 86–89). The apparatus and method for determining as little as 10 mg. of copper to ± 0·3 mg. in the presence of 5 g. of iron are described. For carbon steels, the sample is dissolved in H_2SO_4–HCl mixture with hydrazine sulphate present to maintain the ferrous state, and the internal electrolysis is continued for 30 min. at 75° C. Accurate results were only obtained when additional copper as copper sulphate was added to the solution before the internal electrolysis.—T. E. D.

Method for the Quantitative Determination of Copper in Carbon Steel without Filings. N. V. Tananaev and M. I. Dubova. (*Zavodskaya Laboratoriya*, 1950, No. 2, 231). [In Russian]. In the method described, copper in carbon steels is colorimetrically determined in a solution obtained by placing a few drops of acid in a 5-mm. deep hole drilled in the sample. The pink colour produced by the reaction of bivalent copper with potassium ferrocyanide in acetic acid solution is used, the iron being combined with sodium pyrophosphate.—S. K.

Photometric Determination of Copper in Pig Iron and Unalloyed Steel. W. Werz and A. Neuberger. (*Arch. Eisenhüttenwesen*, 1952, **23**, Jan.–Feb., 37–38). In trying out the Koch-Berens improved photometric copper determination it was established that it is better to precipitate the copper with sodium sulphide in H_2SO_4 than in HCl solution. The yellow colour due to iron carbide does not interfere when a red filter is employed. A procedure has been developed by which the copper content of pig iron and steel can be determined within 35 min., with an accuracy of ± 0·01%.—J. P.

Rapid Photometric Determination of Copper in Steel. W. Koch and K. Behrens. (*Arch. Eisenhüttenwesen*, 1952, **23**, Jan.–Feb., 35–36). A modification of the photometric method for the determination of copper as the ammonium complex is described. It depends on the separation of the copper with sodium sulphide, which prevents interference by chromium, nickel, and cobalt. A determination takes about 30 min.—J. P.

Determination of Nitrogen and Carbon Dissolved in Alpha Iron by Measurement of Damping, as Applied to Mild Steels of Commercial Purity. Å. Josefsson and E. Kula. (*Jernkontorets Ann.*, 1952, **136**, Apr., 63–73). [In Swedish]. The internal friction method was applied to four steel samples. Included impurities such as manganese or phosphorus changed the shape of the internal friction curve for nitrogen, while that of carbon was broadened somewhat. Ageing curves show effects of water quenching, normalizing, and furnace cooling. The fixation of nitrogen by aluminium and its tendency to remain in supersaturated solid solution, even during slow cooling, are described.—G. G. K.

Methods and Apparatus for the Determination of Gases in Metals. K. Rutkowski. (*Hutnik* (Katowice), 1952, **19**, Mar., 95–101). [In Polish]. A survey of methods and apparatus used for the determination of adsorbed and adsorbed gases in metals is given.—V. G.

Principles of Analytical Determination of Gases and Non-Metallic Inclusions in Steel. M. Šicha. (*Hutnické Listy*, 1951, **6**, Oct., 470–483; Dec., 590–594). [In Czech]. A critical survey of the methods used for the determination of gaseous and solid impurity contents in steels is given, based upon the author's own researches and experience with the methods described. Methods for the determination of the total oxygen content, based on weighing, vacuum extraction, Herty's method including photometry, and Gotta's method, are examined, and diagrams and photographs of the author's equipment are shown. With regard to solid inclusions, a modified Stead-Dickenson method for the determination of silica is discussed, and the mercuric chloride method for estimating CaO and MgO is dealt with. Attention is given to the determination of atomic hydrogen in steel and to the methods of sampling liquid steels. The principles involved in the determination of fixed nitrogen are examined. (24 references).—P. F.

The Estimation of Boron in Boronized Metals. G. H. Bush and D. G. Higgs. (*Analyst*, 1951, **76**, Dec., 683–691). Analysis of boron in iron, nickel, cobalt, and copper, in which the metals are removed by mercury cathode electrolysis is described. A method for boronized molybdenum, in which the latter is removed as sulphide is outlined.—T. E. D.

Gravimetric Determination of Molybdenum in Steel with Oxiquinolene. A. Isla Garcia. (*Inst. Hierro y Acero*, 1952, **5**, Jan., *Special Issue*, 73–79). [In Spanish]. A gravimetric method is described for determining molybdenum in the presence of, and in the absence of, vanadium and tungsten, based on precipitation of the molybdate with oxiquinolene.

Studies on the Determination of Molybdenum in Iron and Steel. I—Separation and Determination with Alkali Sulfide. E. Sudô. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Aug., 618–625). [In English]. A method has been developed whereby molybdenum is precipitated and separated with alkali sulphide without using any special equipment. With a sodium polysulphide solution, precipitation is complete in a concentration of 0·1–2·5 *N* H_2SO_4 or HCl. With ammonium polysulphide, the suitable acid concentration is 0·1–0·5 *N*. With potassium polysulphide, the concentration should be 0·5–5 *N* H_2SO_4 or 0·5–4 *N* HCl.—J. G. W.

Studies on the Determination of Molybdenum in Iron and Steel. II—Rapid Determination. E. Sudô. (*Sci. Reports, Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Aug., 626–631). [In English]. A rapid colorimetric method has been successfully developed in which separation with sodium hydroxide is applied in the presence of sodium phosphate, and coloration with stannous chloride and potassium thiocyanate is used. Nickel, manganese, copper, silicon, vanadium, and tungsten have no influence on the determination. The analysis takes 20–25 min. to complete.—J. G. W.

Catalytic Analysis. XIII—Micro-determination of Molybdenum with Ukena's Colorimeter. T. Shiokawa. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Oct., 770–773). In English]. Molybdenum has a catalytic behaviour on the reduction of malachite green to the colourless state with trivalent titanium. A micro-determination of molybdenum was made by measuring the velocity of the catalysed reaction with a colorimeter.—J. G. W.

Determination of Tungsten in Iron and Steel. I—Investigations on the Perchloric Acid Method. H. Gotô and Y. Kakita. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1950, **2**, Oct., 732–740). [In English]. Tungsten can be precipitated quantitatively with a single fuming of perchloric acid by dissolving the sample in aqua regia and evaporating to white fumes after an addition of 50 ml. of perchloric acid. After cooling, 30 ml. of 6*N* HCl are added and brought up to 150 ml. with water, so as to get about 1–1·5 *N* HCl. The solution is heated for 1 hr. at 70–80° C. and filtered. A rapid analysis in 20 min. is possible.—J. G. W.

Determination of Manganese in Steels and Cast Irons without the Use of Arsenous Acid. A. R. Bolein. (*Zavodskaya Laboratoriya*, 1950, No. 2, 232). [In Russian]. In the method described for determining manganese in ferrous metals, arsenous acid is replaced by sodium thiosulphate solution, and the quantity of silver nitrate required as a catalyst has been reduced to a minimum.—S. K.

The Use of a Thermo-Magnetic Method in Carbide Analysis. B. G. Livshits and K. V. Popov. (*Zavodskaya Laboratoriya*, 1950, No. 2, 157–160). [In Russian]. A method for investigating the carbide residues of chromium steels, based on the study of magnetic properties in relation to temperature, is described. The carbide residue, tightly packed in a sealed glass ampule, is heated to the required temperature and transferred, without appreciable cooling, to a coil in a magnetic field of 200 oersteds. The deflections of a galvanometer connected to the coil are plotted against temperature from 20 to 350° C. Steels with up to 4·3% Cr were investigated, and curves were also obtained for rust and impure cementite. Chromium in the residues was determined spectrographically. From an examination of the experimental results it is concluded that a chromium-rich phase, not revealed by X-ray methods, and assumed to be trigonal chromium carbide, is present in the steel containing 1·20% C and 1·84% Cr after soaking at 750 and 800° C.—S. K.

Separation of Zinc from Iron by Electrolysis with a Mercury Electrode. P. P. Tsyb and M. T. Kozlovskii. (*Zavodskaya Laboratoriya*, 1950, No. 2, 147–150). [In Russian]. The

electrolytic method described enables virtually complete separation of zinc from iron to be achieved in one stage for an iron/zinc ratio ≈ 10, two stages being necessary for higher ratios.—S. K.

HISTORICAL

The Old Blast-Furnace at Maryport, Cumberland. H. R. Schubert. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 162). [This issue].

The Metallurgist Johann Conrad Fischer, in the Light of New Research. R. Gnade. (*Giesserei*, 1952, **39**, May 15, 233–234). Recently examined records provide further details about J. C. Fischer's life. His connections with England are pointed out.—J. G. W.

The Georg Fischer "Iron Library" at Schaffhausen. (*Engineering*, 1952, **173**, May 9, 592–593). A description is given of the metallurgical library recently opened to commemorate the 150th anniversary of the iron and steel engineering firm of Georg Fischer, Ltd., Schaffhausen, Switzerland.—M. D. J. B.

Rylands of Warrington. G. K. Rylands. (*Wire Ind.*, 1952, **19**, Apr., 361–371). This is a history of Rylands Bros., Ltd., of Warrington, manufacturers of ferrous wire and wire products.—J. G. W.

ECONOMICS AND STATISTICS

Train Arrivals, Handling Costs, and the Holding and Storage of Raw Materials. M. D. J. Brisby and R. T. Eddison. (*J. Iron Steel Inst.*, 1952, **172**, Oct., 171–183). [This issue].

Outline of the Development of Norway's Iron Industry. U. Styren. (*Blad Berg. Vänner*, 1951, No. 2, 271–307). [In Norwegian]. This is a review of the development of Norway's iron industry and of its fluctuating fortunes. Attempts made with government support to re-establish and expand the industry are outlined, all of which were fruitless because of prevailing economic conditions. Further post-war plans, which envisage a £60 million development programme, are examined.—G. G. K.

BOOK NOTICES

CHALMERS, BRUCE (Editor). "*Progress in Metal Physics.*" Vol. 3. La. 8vo, pp. viii + 334. Illustrated. London, 1952 : Pergamon Press, Ltd., (Price 48*s.*)

The annual appearance of a new volume in the "Progress in Metal Physics" series has now become an event keenly anticipated by a wide circle of readers in the field of metal physics and theoretical and applied metallurgy. The present volume, a collection of eight authoritative reviews of aspects of metal physics which have received considerable attention in recent years, is certain to uphold the high reputation established by its two predecessors.

In the first contribution J. S. Bowles and C. S. Barrett review the crystallographic aspect of phase transformations in the solid state, considering in detail the contributions relating to the atom movement accompanying such transformations, in the transforming material, in the boundaries of the transforming regions, and in the surrounding matrix. Although a considerable amount of work has been done on martensitic as well as nucleation-and-growth transformations, a number of fundamental problems remain yet unsolved. However, it appears likely that the new developments in X-ray techniques, such as the use of micro-beams and Geiger-counter spectrometry, coupled to the recent development in dislocation theory will facilitate a more complete synthesis of the available evidence within the near future.

D. K. C. MacDonald, in the introduction to the second chapter, dealing with the properties of metals at temperatures near the absolute zero, makes the significant point that, although the mechanical behaviour of metals at these temperatures is today technologically of little importance, a fundamental understanding of the physical properties of pure metals and alloys demands a knowledge of, for example, the behaviour of the conduction electrons, the study of which necessitates recourse to very low temperatures. It is self-evident that such fundamental problems cannot be dealt with without the introduction of results from atomic mechanics, yet the author has certainly succeeded in presenting his contribution in a manner that will make it not only enlightening but also enjoyable reading to workers in the applied and academic fields.

In Chapter 3, a review of recent advances in the electron theory of metals, N. F. Mott introduces the reader first to recent views concerning the difference between a metal and a non-metal as interpreted by wave mechanics. This leads to some discussions of magnetic and thermal phenomena in metals ascribed to the behaviour of electrons. He then discusses metallic cohesion, with particular reference to the transition metals, and the increasingly important subject of elastic constants. The problem of alloying is then examined from the point of view of charge distribution on dissolved atoms, which leads to a consideration of the information obtainable by soft X-ray spectroscopy. Finally, a brief review is given of the applications of electron theory to particular kinds of lattice defects. This chapter should be carefully studied by every serious student and worker concerned with physics and metallurgy.

In view of recent controversies relating to resonance phenomena, it is of considerable interest that Mott questions Pauling's use of fractional valencies to account for the cohesion in elements of the long period (including iron), for these, unlike the zone concept, cannot be related to any direct property of the electron model. He equally questions Pauling's attempts to describe cohesion in metals having full *d*-bands, such as copper, nickel, zinc, etc., by means of resonating *d*-orbitals.

The fourth chapter, by R. Clark and G. D. Craig, is devoted to a summary of most of the available literature on twinning. Here, again, a considerable amount of work has accumulated, yet the authors admit that present knowledge of twinning processes is incomplete. This, and the existence of similar gaps in other subjects dealt with in this book, clearly show the uneven development of science and, by implication, point to the need for wider perspectives and for a systematic and detailed approach to a number of problems.

By comparision, the subject of ferromagnetism, ably reviewed by Ursula M. Martius, appears to be in a very satisfactory state, and theory and experiment, at any rate as far as single crystals are concerned, are in good agreement.

The need for more detailed examinations of structural changes in metals, be it from the point of view of alloying, strength, or from the point of view of research on the nature of defects, transformations, creep, etc., renders the inclusion of G. B. Greenough's critical review on quantitative X-ray diffraction observations on strained metal aggregates most appropriate, and should prove particularly useful to the X-ray crystallographer.

In the seventh chapter J. E. Burke and D. Turnbull devote over seventy pages to recrystallization and grain growth. The fundamental question as to the nature of recrystallization nuclei, as in the case of nucleation-and-growth transformation, is obscure, and theories of grain growth and recrystallization have up to now been developed on a formal, semi-empirical basis. Nevertheless, considerable advances have been made in analysing the salient processes involved in these phenomena. It is highly probable that there exist some fundamental features common to creep, recrystallization, recovery, grain growth, and perhaps even fatigue. Burke and Turnbull's paper should thus be of very wide interest. On page 248 the authors consider the "apparently unreasonably large" entropy of activation for grain growth. Such apparently large entropies are also found in creep, together with the tendency of the entropy terms to balance changes of the experimental energy of activation due to variations in alloy contact. These problems merit careful consideration.

In the eighth and final chapter B. Chalmers, the editor of the series, reviews the development of the work on the structure of crystal boundaries, a subject the solution of which provides a most gratifying example of how, by ingenious but comparatively simple methods, a fairly comprehensive picture of the nature of the grain-boundary has been built up.

The critical selection of topics for inclusion in the present volume, the high level of writing throughout, and the large

number of references, make this book a most valuable contribution to the scientific literature of today.

PAUL FELTHAM

CONN, G. K. T., and F. J. BRADSHAW (Editors). "*Polarized Light in Metallography.*" 8vo., pp. xi + 130. Illustrated. London, 1952: Butterworth's Scientific Publications. (Price 21*s.*)

The use of polarized light for transparent objects, such as minerals and rocks, is well established. Application to opaque specimens is less developed, especially quantitatively, and certainly less appreciated. There must be many metallurgists who have little idea of the method and its possibilities with metals. The application is not new, but the information is scattered in the literature, and the reviewer was aware of only one good general, although short, account by Chalmers in 1939. Since that time there have been numerous applications and at least one important development. A book given solely to the subject of metallographic application is, therefore, particularly welcome.

This book is the result of a survey made for the optical Methods Sub-Committee of the British Iron and Steel Research Association. In passing, the Association should be complimented for other similar surveys recently made available in book form. The Editors of the present volume were, respectively, Chairman, and Technical Secretary of the Committee. There are seven chapters by workers with experience in the subject, and a short glossary of optical terms. The first two chapters are by Dr. G. K. T. Conn, one of the Editors, and J. M. Naish; they outline general theory, and form a commendable feature. Chapter 3 by A. F. Hallimond and E. Wilfred Taylor covers equipment and procedure. The actual applications of polarized light are described in the next three chapters; to metal surfaces by E. C. W. Perryman, to inclusions in metals by H. Morrogh, and to opaque ore specimens by E. Cohen. The last chapter by B. W. Mott is in the nature of a summary. Each chapter has been written so that it can be read largely without reference to the others. This is advantageous because most metallurgists will turn first to the chapters by Perryman and Morrogh to see what can be done with polarized light. In all, this little book provides an extremely useful and interesting account of a subject which is increasing in importance, and the volume will undoubtedly stimulate more metallurgists to apply the technique.

A. R. BAILEY

COX, L. L. "*Patternmaking.*" 8vo, pp. ix + 123. Illustrated. London, 1952: Sir Isaac Pitman and Sons, Ltd. (Price 12*s.* 6*d.*)

This book deals in a very practical way with the fundamentals of patternmaking. The author, who is a Lecturer in Patternmaking at the Derby Technical College, has used his experience as a teacher to produce a book which is both clear and concise.

The many practical examples chosen have been carefully selected, starting with the simplest of patterns and progressing gradually to those of comparative complexity. The excellent illustrations help greatly in making the text clear and easy to read. Although the book is concerned mainly with wood patterns and core-boxes, chapters are included on plate work, storing patterns, and patternshop machinery.

This book will undoubtedly be popular with the apprentice and the student, for whom it is intended, and they are advised to work through the series of questions which appear at the end of each chapter. In connection with question ten at the end of chapter five, the reviewer would point out that a British Standard Specification exists covering the colouring and varnishing of pattern equipment.

J. BAMFORD

MAYER, KARL. "*Was der Siemens-Martin-Stahlwerker von seiner Arbeit wissen muss.*" (Stahleisen-Schriften. H.3.) 8vo, pp. 151. Illustrated. Düsseldorf, 1952: Verlag Stahleisen m.b.H. (Price DM. 8.50)

The author of this book has attempted, in the space of about 40,000 words, to cover in considerable detail all the operations which are conducted in an open-hearth steelworks and to describe all the relevant pieces of plant and equipment. The editor of this series of practical handbooks confesses in the preface that it is open to criticism on the score of either having left something out or of giving undue prominence to some particular process which the critic may not consider to be as important as the author does.

Bearing this possible source of weakness in mind the book is otherwise excellent. After a short introduction explaining the importance of iron and steel, the author first describes the various raw materials and alloying additions used in the open-hearth furnace. From here the refractory materials and the construction of the furnace are outlined and then the items such as cranes, ingot bogies, ladles, etc., are all considered.

The remaining two-thirds of the text deal with the actual work performed by the different operators, *i.e.*, scrap loaders, gas plant operators, casting-pit workers, and, finally, melters. The most valuable part of the book is the very clear description of the operations necessary in the casting pit both before and during teeming, though it can be said that perhaps this has been given a little too much prominence.

The book is of course designed to be read by young men who have just entered the field of open-hearth melting as apprentices, and it makes little attempt to cover anything of the chemistry of the operations. Whether this is right or wrong is a question outside the scope of this review. The aim of a book of this type is, presumably, to make better steel melters, and it is difficult to say whether a man becomes better at his job by grasping something of the fundamental nature of the work he does or by studying a series of diagrams showing the various ways in which an open-hearth taphole can be wrongly made up. There are those who would say that the right way to learn this is on the job itself.

D. J. O. BRANDT

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TOLKSDORF, A. "*Was der Kranführer von seiner Arbeit wissen muss !*" Zweite Auflage. (Stahleisen-Schriften, Herausgegeben von H. G. Raskop und K. Mayer. Heft 1.) Pp. 102, Illustrated. Düsseldorf, 1951 : Verlag Stahleisen. (Price DM 5.60)

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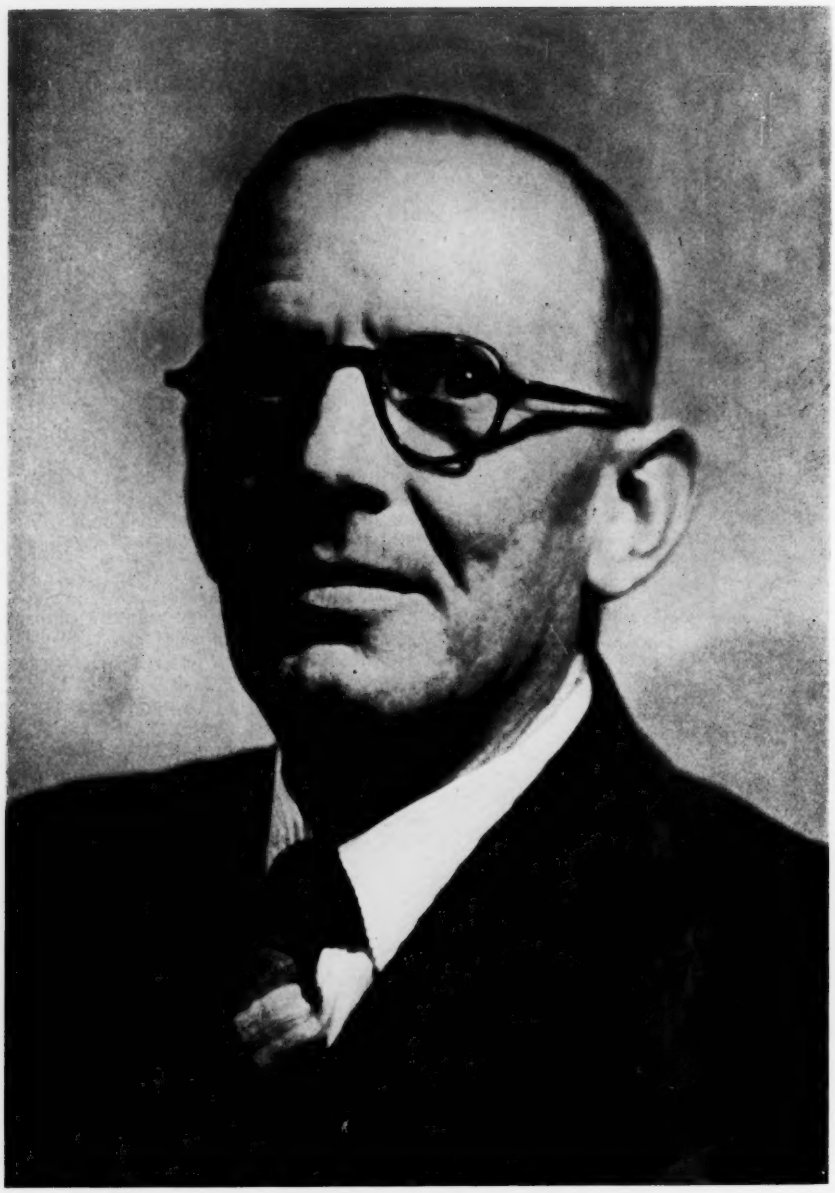
L. A. S. PERRETT, F.I.M.

LAURENCE ARTHUR STEEL PERRETT was born in Briton Ferry, Glamorganshire, in 1900. He was educated at Colston School, Bristol, and later at The Technical College, Swansea, where he was awarded the first Silver Medal in Iron and Steel Manufacture of the City and Guilds.

Mr. Perrett took up his first appointment with The Briton Ferry Steel Company, as a member of their Laboratory Staff. He was engaged on general metallurgical work at The Briton Ferry Steel Works of the Company until 1930, when he transferred to their Albion Works. After varied experience in all Departments, he was appointed Senior Assistant to the Chief Chemist and Metallurgist in 1936. He took up his present appointment as Chief Chemist and Metallurgist in 1940.

Mr. Perrett was a Founder Member of The Swansea Technical College Metallurgical Society, now the Swansea and District Metallurgical Society. He was Joint Honorary Secretary of the Society from 1938 to 1949, and was elected President for the Session 1951-52. He was admitted as a Fellow of the Institution of Metallurgists in 1947, and has been a Member of The Iron and Steel Institute since 1919.



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Honorary Member of Council